Study on Design Method of Diversion Pier in Channel Entrance Area with Complex Flow Characteristics

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Abstract. The entrance area is the main way for ships to enter and exit the approach channel. During the navigation period, the approach channel, the entrance area and the connecting section should avoid turbulence, whirlpool and other bad flow conditions. When conditions are limited and cannot be avoided, engineering or non-engineering measures should be taken to make it harmless to ensure the efficiency and safety of shipping. Aiming at improving the navigation safety effect of the estuary area, this paper analyzes the effect of improvement measures under the actual navigable flow condition by establishing the flow information fitting model and the prediction model of diversion pier setting, and provides the design method and basis for the installation of diversion pier in the estuary area to be predicted. It enriches the model base and knowledge base of the channel entrance area with complex flow characteristics, which has important practical significance and engineering value for shipping safety and waterway management.

Keywords:Entrance area, diversion pier, complex flow, flow information fitting model, prediction model.

1. Introduction

Qingshan Junction is a water conservancy project with a long history, built in the 1960s. The original lock of the hub is a Class VI lock with a designed passing capacity of only 1.2 million tons. However, due to the lack of connection between the upper and lower water levels of the hub, and the simple, low standard and inadequate maintenance and management of the shipping facilities of Qingshan Lock and Yanzhou Lock, the navigation of Qingshan Lock has actually been cut off. Moreover, the navigation conditions of the upper estuary area of the crooked branch of Qingshan Lock are poor, and the unfavorable factors such as the large transverse flow rate, longitudinal flow rate and backflow of the water flow have been formed. It will cause transverse drift and torsion of the ship in the import and export gate area, and serious accidents will occur when the control is out of control, which seriously affects the efficiency and safety of shipping. Therefore, it is of great practical significance to improve the flow condition in the entrance area of the lock approach channel for navigation safety and the navigation ability of the lock.

Research Status at Home and Abroad

1.1 Research Status of Navigable Flow Conditions

Due to the relatively high limit of navigable flow condition required by the code, it is difficult to meet the required value of the code in practical application. Many domestic scholars have done a lot of research work on navigable flow condition: By analyzing the test data of real ships and ship models, Li Yibing et al discussed the navigable flow conditions of the connecting section outside the entrance of the approach channel of the lock, and proposed the flow velocity limit standard that can meet the safety of ships and fleets passing through the connecting section [1]. Zhou Qin et al. combined with practical projects such as Cangxi, Xinxin, Jinxi and Fengyichang junction of Jialing River, further discussed the standard of navigable flow conditions in the entrance area and connecting section of the lock approach channel through hydraulic model test and ship model test, and proposed that the flow control index should be less than 2.6m/s for the Class IV channel in the mountain section. The transverse flow rate is less than 0.4m/s, and the sailing condition is good [2];

Based on two-dimensional flow equation, Zhou Shuqin carried out numerical calculation by finite element method and related physical model test, and analyzed the error of the limit value of navigable flow conditions in the entrance area of the approach channel, and proposed that the accuracy requirements could be met when the error was controlled within ±0.05m/s [3]. Zhao Zhizhou took the main hub of Wujiang River as the prototype, established the generalized building model of the navigable hub of the curved gorge river, and proposed the layout of navigable buildings suitable for the navigable conditions of the curved river [4]. Chen Zuoqiang summarized the problems existing in the current navigable flow condition standard, and based on different regions and channel grades, studied the navigable flow conditions in the entrance area and connecting section of the navigable building approach channel under different arrangements through physical model tests, ship model tests and field water flow test tests, and proposed corresponding flow condition limits [5]. In addition, the United States Army Corps of Engineers has conducted research on cascade avionics engineering in the Tennessee Valley [6]. France, Germany respectively on the Rhone river and Rhine River and other river cascades development and nearby waterway regulation, the research institutions of these countries have also carried out some research, obtained certain research results.

1.2 Research Status of Improvement Measures for Navigable Water Flow in Port Area

In order to improve the navigation conditions of the entrance area of the approach channel, some scholars have proposed corresponding improvement measures based on specific hub examples from the aspects of reducing the Angle between the flow direction and the route, reducing the flow velocity and improving the flow pattern of the entrance area. However, no matter what kind of improvement measures are adopted, the causes of adverse flow patterns in the entrance area of the upper and lower approach channels must be analyzed and studied. Finally, according to the causes, take corresponding measures to optimize.

So far, there have been many kinds of structures in the form of guide wall structures to improve the flow conditions in the mouth and gate area at home and abroad, such as permeable navigation wall, permeable water barrier wall, perforated diversion pier and floating diversion divee, etc. The most commonly used research methods are mostly physical model test and numerical simulation research. Li Juntao made a regular study on the influence of diversion pier on the adverse flow pattern in the entrance area under the condition of narrow and continuous curved river channel based on practical engineering [7]. Yang Yu effectively solved the problem of high flow velocity in the reflux area by adding diversion dike and digging beach in the mouth area [8]. Wang Yunli elaborated the formation mechanism of adverse flow return and oblique flow in the mouth and gate area, and introduced the mechanism of improvement measures of adverse flow. He found that among the engineering measures, the three engineering measures, especially the opening of navigation dike, the layout of diversion pier and the construction of Dinghe dam, were the best [9]. Li Jinhe improved the flow pattern in the mouth area by arranging the diversion pier and increasing the length of the diversion dike, and found that the length of the diversion dike would have a great influence on the flow condition, and the diversion pier could effectively reduce the diffusion and development of water flow [10]. Pu Xiaogang analyzed the flow conditions of the upstream and downstream approach channel of Tugu Pond and found that the combination of diversion dike expansion and diversion pier could improve the flow effect more effectively [11]. Bai Chengshao made numerical simulation on the improvement of oblique flow at the end of the bifurcated river, and found that parallel placement of parallel DAMS or diversion piers at the end of the river could not effectively improve the size of the transverse flow, and it was necessary to combine various engineering measures to effectively improve the oblique flow [12].

To sum up, many scholars at home and abroad have studied the improvement measures of navigable flow in the mouth area, and relatively many achievements have been achieved. However, there are relatively few studies on the mouth area of the lock in the complex conditions-curved branching river, and the installation position of the diversion pier needs to be manually measured, resulting in greatly reduced efficiency.

2. Construction of Design Model of Diversion Pier in Port Area

2.1 Research on Water Flow Information Fitting Model

The water flow information obtained from multiple historical channel mouth areas mainly includes: historical lateral flow velocity, historical longitudinal flow velocity, historical flow back length, and historical flow back velocity.

Integrate water flow information into a collection of historical water flow information:

$$\{\{A_1, B_1, C_1, D_1\}, \{A_2, B_2, C_2, D_2\} \cdots \{A_i, B_i, C_i, D_i\}\} \quad (1)$$

Then the fitting value of water flow information is:

$$\max_i(\Delta A, \Delta B, \Delta C, \Delta D) = \max_i\left((A_i - A'), (B_i - B'), (C_i - C'), (D_i - D')\right) \quad (3)$$

$$\mathrm{mix}_i(\Delta A, \Delta B, \Delta C, \Delta D) = \mathrm{mix}_i\left((A_i - A'), (B_i - B'), (C_i - C'), (D_i - D')\right) \quad (4)$$

Where$\max_i(\Delta A, \Delta B, \Delta C, \Delta D)$is the maximum fit value,$\mathrm{mix}_i(\Delta A, \Delta B, \Delta C, \Delta D)$ is the minimum fit value, $A_i$is the I-th transverse velocity of the historical flow in the historical flow information set,B_i is the I-th longitudinal velocity of the historical flow in the historical flow information set, C_i is the I-th return length of the historical flow in the historical flow information set,D_i is the I-th return velocity of the historical flow in the historical flow information set,A'Is the lateral velocity of the water flow,B' Is the longitudinal velocity of the water flow,C' is The reflux length of the water flow,D' Is the return flow rate of the water flow,ΔA Is the difference value between A_i and A',ΔB Is the difference value between B_i and B',ΔCIs the difference value between C_i and C',ΔD Is the difference value between D_i and D'.

In order to reduce the error of the flow information fitting model and set the error elimination factor, the flow information fitting model is specifically:

$$\max_i(\Delta A, \Delta B, \Delta C, \Delta D) = \max_i\left(p(A_i - A'), q(B_i - B'), r(C_i - C'), g(D_i - D')\right) \quad (5)$$

$$\mathrm{mix}_i(\Delta A, \Delta B, \Delta C, \Delta D) = \mathrm{mix}_i\left(p(A_i - A'), q(B_i - B'), r(C_i - C'), g(D_i - D')\right) \quad (6)$$

Where p, q, r and g are the error elimination factors, which are used to ensure that is positive and dynamically adjust the value of $\Delta A, \Delta B, \Delta C, \Delta D$.

2.2 Research on Prediction Model of Diversion Pier Setting

By obtaining the information of historical diversion pier corresponding to the entrance area of each historical channel, the information set of historical diversion pier mainly includes: the number of historical diversion pier, the setting Angle of historical diversion pier and the spacing of historical diversion pier, the information set of historical diversion pier is generated. Through the flow information fitting model, the flow information is compared with the historical flow set one by one, and the minimum fit value and maximum fit value are generated to the diversion pier. The prediction model is set as follows:

$$\mathrm{Sim}(M, N) = \frac{\sum_{i=1}\left(\left(\{A', B', C', D'\} - \mathrm{mix}_i(\Delta A, \Delta B, \Delta C, \Delta D)\right)\left(\{A_i, B_i, C_i, D_i\} - \max_i(\Delta A, \Delta B, \Delta C, \Delta D)\right)\right)}{\sqrt{\sum_{i=1}\left(\{A', B', C', D'\} - \mathrm{mix}_i(\Delta A, \Delta B, \Delta C, \Delta D)\right)^2}\sqrt{\sum_{i=1}\left(\{A_i, B_i, C_i, D_i\} - \max_i(\Delta A, \Delta B, \Delta C, \Delta D)\right)^2}} \quad (7)$$

Where, M is water flow information, and N is the historical water flow information most similar to M.

Combining the minimum fit value, the maximum fit value, the flow information and the historical flow information set, calculating the similarity between the flow information and the historical flow information in the historical flow information set, and finding out the historical flow information that is most similar to the flow information, Determine the most similar historical diversion pier information corresponding to the most similar historical flow information, and according to the most similar historical diversion pier information, set the diversion pier at the mouth area of the river channel to be predicted.

3. Model Test and Analysis

According to the study on the navigable flow information and diversion pier information of Qingshan Junction, the combined conditions of all incoming flow of left branch (total flow of left branch 8910m3/s) + total incoming flow of branch channel 100m3/s and 1600m3/s (total flow of left branch 2200m3/s) + total incoming flow of branch channel 100m3/s are considered. It is verified by model test. The design unit adopts the measures of enlarging the section gradually, three-level energy dissipation and blocking pier to control the influence of the incoming flow on the navigation condition of the entrance area of the lock approach channel. The original design adopts six flow barrier piers with unequal spacing (figure 1).

In the model test, two combined conditions were considered: the total flow of left branch (8910m3/s) + the total flow of branch (100m3/s) and the total flow of left branch (1600m3/s) (2200m3/s) + the total flow of branch (100m3/s).

The test results show that:

1) When the left branch is fully open to incoming flow (total flow of left and right branches 8910m3/s) + the branch inlet total flow of 100m3/s, the branch inlet flow after 3 levels of energy dissipation (the bottom elevation of the last level 1 stilling pool 35.0m, Lower than the bottom elevation of the approach channel 37.0m), the flow from the branch channel mouth enters the entrance area of the approach channel in the way of bottom flow, which has little effect on the surface flow field of the entrance area of the approach channel.

2) When the inflow of left branch is 1600m3/s (the total flow of left and right branches is 2200m3/s) + the total inflow of branch gully is 100m3/s, the outflow of the first baffle pier and the bank, and the outflow of the first baffle pier and the second baffle pier are more concentrated, and the direction is nearly perpendicular to the direction of the approach channel, and the outflow of the following empty piers gradually decreases and becomes smooth (figure 1). Because the flow rate is small and the flow pattern is more chaotic, the instrument measurement is not convenient, and the measurement result using the buoy is roughly 0.40m/s ~ 0.60m/s.

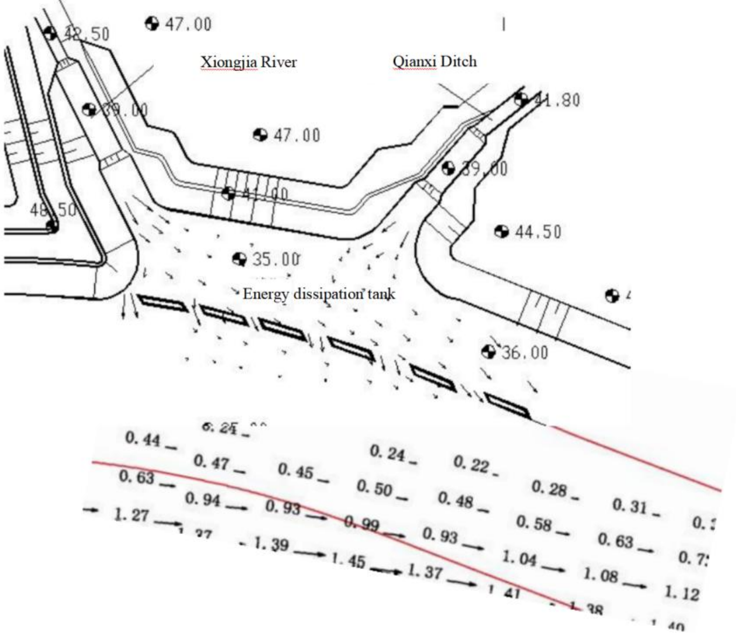

Figure. 1. Original design scheme of Xiongjia River and Qianxi Ditch outlet (6 flow isolation piers) and local flow field diagram (flow combination: 2200m³/s+ 100m³/s branch ditch).

3) According to the above situation, the diversion dam +1 barrier pier is optimized and modified (figure 2). After the modification, the incoming flow at the branch trench is basically connected

with the main stream at the mouth area smoothly, and at the same time, it is hedged with the main stream, which can slow down the oblique flow in the approach channel to a certain extent.

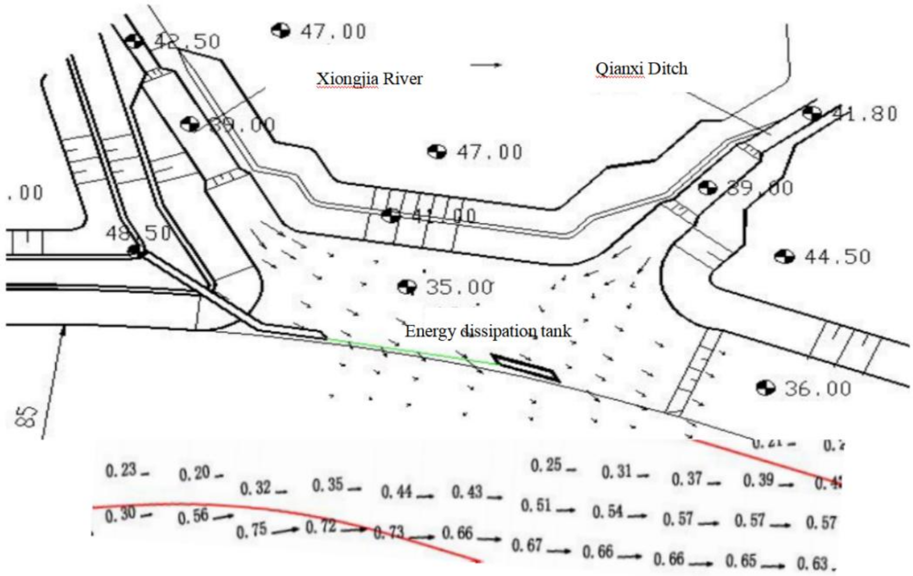

Figure. 2. Xiongjia River and Qianxi Ditch outlet modification plan I (diversion dam +1 barrier pier) and local flow field diagram (flow combination: 2200m³/s+ 100m³/s branch ditch).

Under the condition that the left branch sluice is fully opened, the longitudinal and transverse velocity of the entrance area and the connecting section of the downstream approach channel of the lock meet the requirements of navigable flow conditions. However, the ship model test shows that when the ship sails down from the port area, due to the large distance between the first stage diversion pier and the solid navigation wall, and the large fault opening towards the main stream of the river, the main stream enters the approach channel and forms oblique diffusion flow. Affected by this, the ship model is easy to deviate to the Xiongjia River, the diversion pier of the mouth of the Qianxigou River and the channel edge. Therefore, reducing the distance between the diversion pier and the solid navigation wall can effectively reduce the security risks.

4. Conclusion

In order to construct the design model and method of the diversion pier in the estuary area, this paper analyzes the flow information and diversion pier information, studies the construction of the flow information fitting model and the prediction model of diversion pier setting, and verifies the design method through the analysis of the relevant waters of Qingshan Junction, providing a research basis for the design and optimization of navigable buildings in the construction and renovation aspects. At present, Bridges and other cross-river buildings constructed on the curved channel will also produce turbulent vortex areas, which will also have adverse effects on ship navigation. With more in-depth research, the results will also play a theoretical guiding role in the location and arrangement of Bridges and other buildings in practical engineering.

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