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Analysis of navigation flow conditions in the entrance area of the Babao ship lock of Hangzhou section of Jinghang Grand Canal

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Abstract. In this paper, we used typical riverbed topography and hydrodynamic conditions, combined with the arrangement of the Babao ship lock exit guiding wall and three tidal gate construction schemes, to calculate the planar flow regime for the exit channel area. In addition, the variation of the planar flow field at typical moments in local outside the entrance area, the size of the recirculation region, the lateral flow velocity, and the longitudinal flow velocity in the outlet channel are used to analyze and compare the navigational flow conditions of different schemes. The calculation shows that the magnitude and direction of the mainstream flow outside the guiding wall are basically unchanged after the construction of tidal gates. Out-of-port flow patterns are not related to whether or not tide gates are built, and the impact of building gates is primarily in the waters inside the head of the guiding wall. Compared with and without a tidal gate, the time required for transverse velocity to meet navigational requirements is less for each scheme.

1. Introduction

In order to alleviate the contradiction between the rapid growth of the traffic volume of the Grand Canal and the incompatibility of the passage capacity of the waterway, and to fundamentally solve the problem of canals' traffic congestion and the navigation bottlenecks of the city rivers, it is urgent to carry out the three-level waterway improvement project in the Zhejiang section of the Grand Canal, of which the Babao ship lock is one of the key projects^[1]. The outlet of the Babao ship locks is located at the Qibao bend in the estuary of the Qiantang River, and the river in the entrance area is subject to the joint action of runoff and tide, strong hydrodynamics, high sand content, and complex river channel evolution, which are very unfavorable to lock construction and navigational conditions^[2]. Current research methods for navigational flow analysis in the lock entrance area usually include field measurements^[3,4], physical modeling^[5,6], and numerical modeling^[7-9]. In this project, a planar 2D numerical model is established to calculate and analyze the flow characteristics and planar flow under typical riverbed topography and hydrodynamic conditions after the implementation of the lock gate arrangement, which provides a scientific basis for further optimizing the gate arrangement and proposing desilting engineering measures.



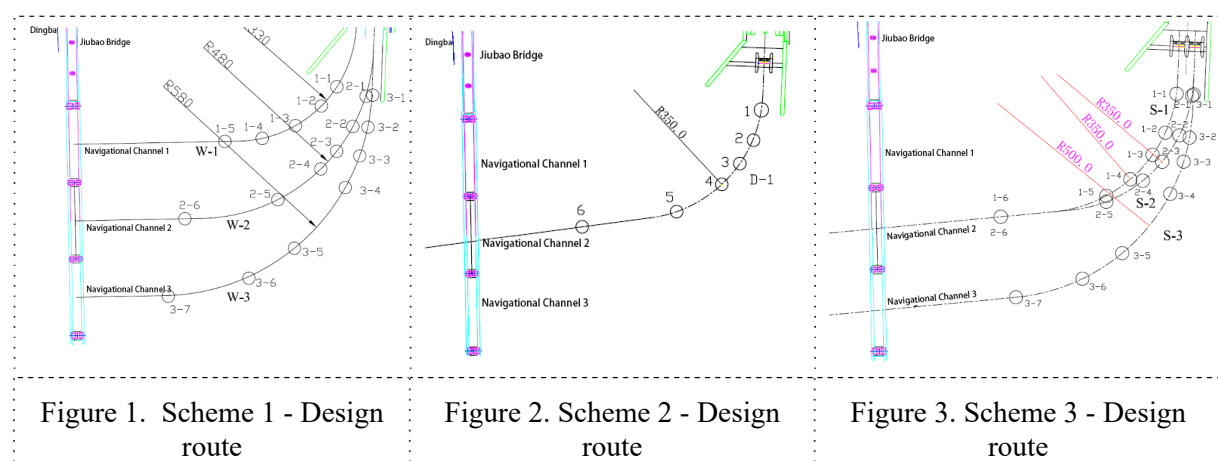
2. Water flow conditions and calculation of conditions

2.1. Water flow conditions

A planar two-dimensional mathematical model is used to calculate and compare three tidal gate schemes considering two different types of upstream and downstream boundary and topographic conditions. The adverse conditions during the flood are the first type of model conditions, which is represented by the upstream Fuchunjiang power station flow of $4500 \text{ m}^3/\text{s}$, the downstream Cangqian tidal range of 10% and 50% during the flood, and the topographic conditions with a small riverbed volume before the flood. Tidal adverse conditions as Type II model conditions, i.e., upstream power plant flow with a multi-year average flow of $952 \text{ m}^3/\text{s}$, downstream pre-barn tidal processes with 10%, 50%, and 90% tidal range, and topographic conditions with large riverbed volumes after high tidal floods. The flow field after the implementation of the three tidal gate schemes is calculated for the two topographic and hydrodynamic combination boundary conditions described above.

2.2. Calculation of working conditions

There are three schemes for tide gates: Scheme 1 is no tide gate (Figure 1), Scheme 2 is a single-gate tide gate (Figure 2) with a gate width of 30m, and Scheme 3 is a double-gate tide gate (Figure 3) with a single gate width of 30m. This section of the waterway is a Class III waterway. During the navigation period, the maximum water surface velocity at the entrance gate area should meet the requirements of Class III navigation channel in the "Inland Waterways Navigation Standard (GB50139-2014)", that is, the maximum longitudinal velocity (longitudinal velocity) should not be greater than 2.0 m/s , transverse velocity (transverse velocity) should not be greater than 0.30 m/s , return flow rate not exceeding 0.4 m/s . In order to analyze the magnitude of longitudinal and transverse velocities in the entrance gate, it is necessary to determine the course of the ship in the entrance gate and to take some representative points on the course for the counting. The main route mainly considers the centerline of the main navigation channels of the Jiubao Bridge, the axis of the approach channels, and the centerline of the channels determined by the minimum turning radius required by the design. The route quotes the information provided by the engineering designer: one route for the single-gate solution and three routes for the double-gate solution. The specific route diagrams are shown in Figures 1 - 3. Each route has 5-7 representative points, and the analysis of the magnitude of the flow velocity is mainly based on these representative points.



3. Analysis of navigational water flow conditions at the ship lock entrance area

3.1. Analysis of flow regime at ship lock entrance area

The tidal current fields at the maximum ebb tides for the upstream $952 \text{ m}^3/\text{s}$ flow, downstream 10% tidal range, without gate, single-gate and double-gate schemes are shown in Figures 4, 5 and 6. The

flow direction is basically perpendicular to the bridge axis, and the flow pattern is smoother; due to the ski-jump effect of the guiding wall, the flow velocity inside the guiding wall is generally smaller than the mainstream flow velocity of the river; at the edge of the guiding wall, in the direction of the river channel, the flow velocity gradually increases, and the maximum mainstream flow velocity of the river channel is about 1.4m/s. The distribution of flow velocities outside the guiding wall is similar for all three schemes. This means that the guiding wall and the gate type of the tidal gate have little influence on the channel mainstream.

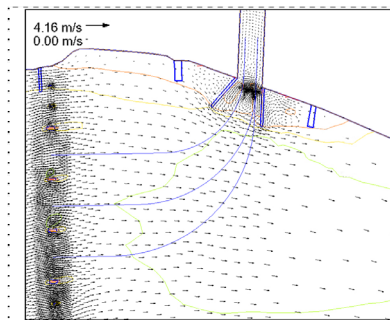


Figure 4. Scheme1 - flow regime at the maximum ebb tides

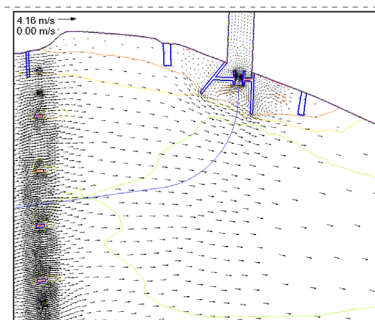


Figure 5. Scheme2 - flow regime at the maximum ebb tides

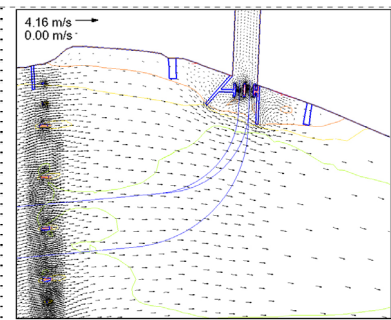


Figure 6. Scheme3 - flow regime at the maximum ebb tides

3.2. Analysis of flow regime inside the guiding wall

Inside the guiding wall, the flow regime changes significantly due to the blocking effect of the tidal gate and the change in the number of gates. Figure 7 (a), (b), and (c) shows the comparison of tidal current fields at the maximum ebb tides in the local area inside the guiding wall for different schemes. It can be seen that in the absence of the tidal gate, there is a large circulation inside the guiding wall, with a maximum circulation velocity of 0.88m/s, while in the single-gate scheme, due to the blockage of the tidal gate, the scale of the circulation decreases and the circulation velocity decreases, with a maximum circulation velocity of 0.56m/s. In the double-gate scenario, there is still a circulation in the tidal gate, and a part of the circulation flows from the east gate to the west gate, forming a closed-loop loop with a maximum loop velocity of 0.61 m/s.

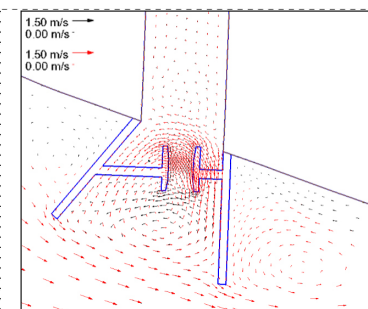


Figure 7 (a). No-gate (red) and single-gate (black) schemes

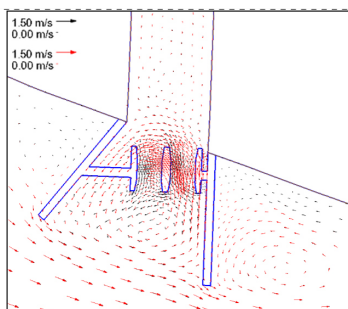


Figure 7 (b). No-gate (red) and double-gate (black) schemes

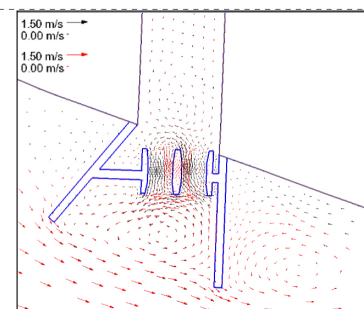


Figure 7 (c). Single-gate (red) and double-gate (black) schemes

The flow velocity after one hour of tide reaching the center point of each gate for single-gate and double-gate schemes and the center point of the section without tide gates is shown in Figure 8. It can be seen that when there is no tide gate, the cross-section is relatively large, the amount of water passing through the gate is large, the range of circulation is relatively large, and thus the flow velocity

is relatively large. After the construction of the tidal gate, the cross-section is reduced, the amount of water passing through the gate is reduced, the range of circulation becomes smaller, and the flow velocity of the gate is significantly reduced. The over-water cross-section in the double-gate scheme is larger than in the single-gate scheme so that the flow velocity at the center of the two gates in the double-gate scheme is generally slightly larger than the flow velocity at the center of the gate in the single-gate scheme.

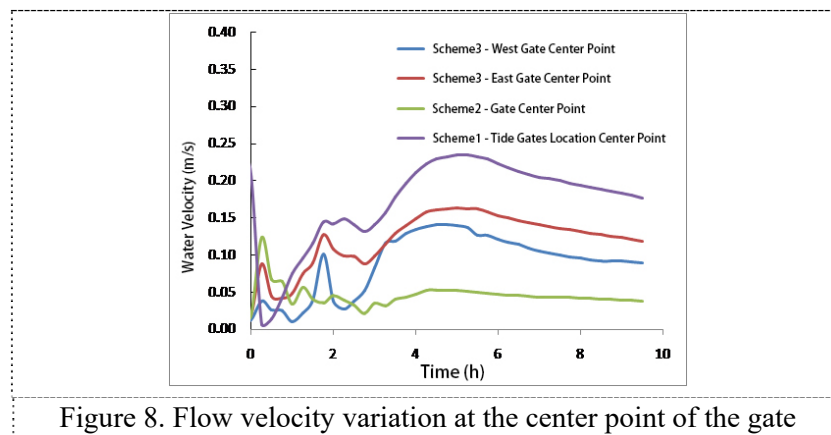


Figure 8. Flow velocity variation at the center point of the gate

3.3. Statistical Analysis of Navigation Velocities

To better analyze the changes of the flow field near the outside of the guiding wall during the tidal process, statistical data on the transverse velocity and longitudinal velocity of each representative point on each course were obtained, and the lengths of time during which the transverse velocity at the representative points meet $\leq 0.3\text{m/s}$, $\leq 0.4\text{m/s}$, $\leq 0.5\text{m/s}$, and $\leq 0.8\text{m/s}$ and the transverse velocity $\leq 2.0\text{m/s}$ during a tidal process were analyzed. From the statistical results, we can see that the navigational conditions are generally good at each point inside the guiding wall from the results of transverse velocity on each route; at the outside of the guiding wall, the flow velocity is generally larger due to the influence of ski-jump, and because the course is nearly perpendicular to the flow direction, the transverse velocity is close to the flow velocity, thus the navigational condition is poor. Along the course from the guiding wall to the mainstream area of the river, because the angle between the course and the flow direction gradually decreases, the transverse flow speed of each representative point gradually decreases, and the time to meet the navigational requirements gradually increases. In the straight-line section after the turn is completed, the course and the flow direction are nearly parallel, the transverse velocity is small, and the time to meet the navigational requirements is over 11 hours, which is the same rule for different routes. For a route, its navigation time is controlled by the shortest time on the route to meet the navigation requirements, and the shortest navigation time for different routes is counted here. Tables 1 and 2 show the shortest time to meet the navigational requirements of different routes for the 2002 topography, upstream $952\text{ m}^3/\text{s}$, and downstream 10% and 50% difference in tidal range, respectively. The shortest navigational time for 3 routes (single-gate route, double-gate S-1, S-2 route, no-gate W-2 route) to meet each current flow velocity is not significantly different. The difference between the double-gate S-3 route and the no-gate W-3 route is not significant in terms of the shortest navigational time for each flow velocity. This means that in the case of the existing guiding wall, regardless of whether the tidal gate is built and the tidal gate is installed with a single or double gates, its impact on the flow conditions of navigation is not significant.

Table 1. Minimum time to meet navigational requirements on different scheme routes (h)

Scheme	Route	2002 Topography +952m ³ /s+10% Tidal Range			
		Less than 0.8m/s (h)	Less than 0.5m/s (h)	Less than 0.4m/s (h)	Less than 0.3m/s (h)
Single-Gate	D-1	1.9	1.2	1.0	0.9
	S-1	2.0	1.2	1.0	0.9
Double-Gate	S-2	2.0	1.2	1.1	0.9
	S-3	1.8	1.2	1.0	0.8
	W-1	3.5	1.4	1.2	1.0
No-Gate	W-2	1.8	1.1	0.9	0.8
	W-3	1.7	1.1	0.8	0.8

Table 2. Minimum time to meet navigational requirements on different scheme routes (h)

Scheme	Route	2002 Topography +952m ³ /s+50% Tidal Range			
		Less than 0.8m/s (h)	Less than 0.5m/s (h)	Less than 0.4m/s (h)	Less than 0.3m/s (h)
Single-Gate	D-1	3.7	1.5	1.1	0.8
	S-1	3.7	1.6	1.1	0.8
Double-Gate	S-2	3.7	1.6	1.2	0.9
	S-3	3.6	1.5	1.2	0.9
	W-1	6	1.8	1.2	0.9
No-Gate	W-2	3.8	1.5	1.1	0.8
	W-3	3.6	1.5	1.1	0.8

4. Conclusions

After the construction of a tidal gate (single-gate, double-gate), there is no change in the velocity and direction of the mainstream flow outside the guiding wall, and the flow regime outside the entrance area is not related to the construction of a tidal gate. The impact of building a tidal gate at the entrance area has no effect on the mainstream flow outside the head of the guiding wall. With or without a tidal gate, the time to meet the navigational requirements of transverse velocity is shorter for each scheme. The duration of the transverse velocity below a certain level on a similar route was not much difference between different schemes. When there is no tidal gate, there is a large return flow in the guiding wall, and the maximum return flow velocity is 0.88m/s; after the construction of the tidal gate, the scale of return flow is reduced, and the return flow velocity is also reduced, and the maximum return flow velocity in the guiding wall area is about 0.60m/s for both single and double gates.

Acknowledgment

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