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Characteristic Analysis of Navigable Flow Conditions and Numerical Simulation of Water Conservancy in Steep Bay Section of the Navigable Tunnel

Xiaolong Cheng[1,2*], Xujin Zhang[2,3], Jun Wu[3]

[1] Chongqing Jiaotong University, Chongqing 400074, China
[2] Chongqing Water Resources and Electric Engineering College, Chongqing 402160, China
[3] Chongqing Southwest Research Institute for Water Transport Engineering, Chongqing 400016, China

Corresponding Author Email: zg.cxl@foxmail.com

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ABSTRACT

Compared with traditional low-standard ship locks, large-section navigable tunnels have the advantages of increasing water resources dispatching, increasing ship crossing channels and shipping. It is necessary to explore the characteristics of navigable flow conditions under the condition of navigable tunnel and study effective measures to improve the navigable flow conditions at the entrance of approach channel of navigable tunnel in steep bay section. However, the existing research results neglect the navigation channel layout in the steep bay section, and it's lack of theoretical research on improving the flow conditions at the entrance of approach channel of navigable tunnel in the steep bay section. For this, this article studies the characteristics of navigation flow conditions and numerical simulation of water conservancy in steep bay section of the tunnel. Firstly, the physical model of tunnel navigation in steep bay section is designed to ensure the geometric similarity, flow movement similarity and dynamic similarity between the model and the actual situation in steep bay section. Then, the numerical simulation of navigation water conservancy in steep bay section of tunnel is carried out, and the continuity equation and momentum equation in the new coordinate system are given. This article explores the navigation scheme of large cross-section navigable tunnel in order to obtain effective measures to improve the navigation conditions of this section. Finally, the corresponding experimental results and analysis are given.

1. INTRODUCTION

With the rapid development of China's economy and the increasing demand for inland navigation, China faces the gradually increasing navigation pressure, and more and more special navigation channel construction schemes are put on the agenda to solve the outstanding shipping problem of low efficiency of crossing gates [1-12]. Compared with the traditional low-standard ship locks, the large-section navigable tunnel has the advantages of increasing water resources dispatching, increasing ship crossing channels and shipping [13-16].

Navigable tunnels are usually set in curved rivers with complex flow patterns and uneven velocity distribution. Because the navigable flow in restricted waters has the characteristics of high wave and rapid velocity, the navigation process of ships is vulnerable to have many adverse effects on the buildings and facilities on both sides of the river, the sediment of rivers and its own navigation stability [17-21]. Therefore, it is necessary to explore the characteristics of navigable flow conditions under the condition of navigable tunnel and study effective measures to improve the navigable flow conditions at the entrance of approach channel of navigable tunnel in steep bay section.

In order to fill in the blank of the research on the key technologies of ship navigation safety in navigable tunnels, the study of Deng et al. [22] establishes a numerical model based on FUNWWAVE-TVD, an open source software package of completely nonlinear Boussinesq equation, to demonstrate the traveling wave motion of ships in navigable tunnels in linear canals. This study provides a reference and basis for the design of single-track straight channel navigable tunnel, and provides a theoretical basis for formulating any key technical standards or specifications for ship navigation safety in navigable tunnel. Based on the typical riverbed topography and hydrodynamic conditions, combined with the layout of the exit guide wall of Babao Ship Lock and the construction scheme of three tidal gates, Yang et al. [23] calculated the plane flow pattern in the exit channel area. In addition, it uses the variation of plane flow field at typical local time outside the entrance area, the size of backflow region, the lateral velocity and longitudinal velocity in the entrance channel to analyze and compare the navigation flow conditions of different schemes. Böttner et al. [24] carried out physical model tests, and designs and constructs a scale model (1:40) to carry two laser Doppler velocimetry sensors and provide optical channels at different positions of the hull to detect the water flow near the bottom of the hull and solve the boundary laminar flow at the hull. Wu and Ding [25] established the physical model of Jiaogang Shiplock. Through model test, the flow situation of lock chamber and approach channel is studied. The results show that when the upstream water level remains high and the difference between upstream and downstream water levels is less than 0.5 m, the annual spring tide discharge and mainstream oscillation during backflow are small.

Scholars at home and abroad have carried out a large number of studies on the flow movement law in the sharp bay section, including the analysis of flow velocity distribution and resistance distribution in the sharp bay section by means of observation, flume test and solid generalized model. However, the existing research results neglect the navigation channel layout in the steep bay section, and it's lack of theoretical research on improving the flow conditions at the entrance of approach channel of navigable tunnel in the steep bay section. For this, this article studies the characteristics of navigation flow conditions and numerical simulation of water conservancy in steep bay section of tunnel. Firstly, in the second chapter, the physical model of tunnel navigation in steep bay section is designed to ensure the geometric similarity, flow movement similarity and dynamic similarity between the model and the actual situation in steep bay section. Then, in the third chapter, the numerical simulation of navigation water conservancy in steep bay section of tunnel is carried out, and the continuity equation and momentum equation in the new coordinate system are given. The fourth chapter explores the navigation scheme of large cross-section navigable tunnel in order to obtain effective measures to improve the navigation conditions of this section. Finally, the corresponding experimental results and analysis are given.

2. PHYSICAL MODEL DESIGN OF TUNNEL NAVIGATION IN STEEP BAY SECTION

Constrained by boundary conditions such as topography, the flow conditions in the steep bay section are more complex, and the flow conditions in the entrance area of the approach channel of the navigable tunnel in the steep bay section affected by oblique flow at the head of the diversion dike and discharge from the sluice gate will be more complex. In this article, the Shipai Project between the Three Gorges Dam is taken as the main research object, and the navigable flow conditions in the entrance area of the approach channel of the lower navigable tunnel in steep bay section are studied in detail.

From the aerial photography of the Yangtze River on the south side of Shipai, it can be clearly seen that the Yangtze River is just in Shipai, turning a very hard bend to the right, and showing a sharp bay of 90 degrees. If you look at the latest map of China, this bend lies between the Three Gorges Dam and Gezhouba Dam. Sixty years ago, the rushing Three Gorges was still the most convenient passage into Sichuan, and Shipai was just waiting at the easternmost end of this passage. The riverbed elevation drops and rises steeply, the width of the river reach is about 345m, the curvature radius of the bend is about 750m, and the water depth is about 90m, so it is difficult to implement the general regulation measures. At the same time, the river surface of steep bay section in Shipai reach is narrow in flood season, which has the problem of insufficient hub layout width. At the same time, due to the influence of bend flow and trajectory-bucket flow, the navigation flow conditions are poor, which will make it difficult for upstream and downstream ships to enter and exit the approach channel, and the risk of safe navigation is huge.

In order to put forward new regulation measures to improve the navigable flow conditions in this section, it is necessary to comprehensively consider the river regime conditions in this area and the setting requirements of water control projects, further explore the characteristics of water flow conditions in the entrance area of approach channel under different navigation schemes, and accurately judge whether the water flow conditions under this scheme meet the requirements of safe navigation of ships.

According to the research purpose and the requirements of physical model experiment and based on the actual conditions of navigable channel characteristics, riverbed morphology and topography in the steep bay section, the physical model constructed is determined as a 1:100-scale integral fixed bed normal model. The model design needs to abide by the gravity similarity criterion and ensure the geometric similarity, flow movement similarity and dynamic similarity between the model and the actual situation in the steep bay section.

Geometric similarity is to ensure that the spatially corresponding size ratio between the constructed physical model and the actual situation of navigation at the approach channel entrance area of the navigation tunnel is constant. Assuming that the plane scale is represented by μ_K, the vertical scale is represented by μ_F, the actual length of the sharp bay section is represented by K_E, and the model length is represented by K_n, then:

$$\mu_K = \mu_F = \frac{K_e}{K_n} \tag{1}$$

Flow movement similarity means that the physical model constructed is geometrically similar to the navigable flow velocity field in the entrance area of the approach channel of the navigable tunnel. Assuming that the velocity scale is expressed by μ_u, then:

$$\mu_u = \mu_K^{\frac{1}{2}} \tag{2}$$

Dynamic similarity means that all the forces at the corresponding points of the physical model constructed and the entrance area of the approach channel of the navigable tunnel are parallel to each other and the magnitude ratio is constant. Assuming that the forces acting on the corresponding points in the entrance area of the approach channel of the navigable tunnel are represented by G_E and the forces acting on the model are represented by G_N, then:

$$\mu_G = G_e / G_N \tag{3}$$

In addition to the above three similarities, the normal fixed bed model also needs to meet a series of limiting conditions. Assuming that the flow resistance coefficient is expressed by g_e, $g_e=2hm^2/s^{1/3}{}_e$, the following equation gives the inequality of the limiting conditions of the resistance square region:

$$\mu_F \le 4.22\left(\frac{U_E F_E}{\alpha}\right)^{2/11} g_E^{8/11} \mu_K^{8/11} \tag{4}$$

Turbulence limiting conditions are given by the following formula:

$$Sp_m = \frac{US}{u} \ge 1000 \tag{5}$$

3. NUMERICAL SIMULATION OF NAVIGATION WATER CONSERVANCY OF STEEP BAY SECTION TUNNEL

The mathematical model has the advantages of short experimental period, no scaling effect and high simulation efficiency. Furthermore, based on the DELFT3D model, this article establishes the navigable flow model in the entrance area of the approach channel of the navigable tunnel in steep bay section, studies its flow characteristics, and makes a detailed study on how to improve its flow conditions. Firstly, the basic equation of two-dimensional flow motion in the entrance area of the approach channel of the navigable tunnel in steep bay section are constructed in the following rectangular coordinate system, and the equation is only applicable to the ideal boundary situation. Assuming that plane coordinates and time are represented by *a*, *b* and *o*, water level and water depth are represented by *F* and *f*, respectively, the components of vertical average velocity in *a* and *b* directions are represented by *v* and *u*, and the drag coefficient and turbulent viscosity coefficient are represented by *D* and *α*, the following equations of flow continuity and flow motion are given:

$$\frac{\partial F}{\partial o}+\frac{\partial vf}{\partial a}+\frac{\partial uf}{\partial b}=0 \tag{6}$$

$$\frac{\partial v}{\partial o}+v\frac{\partial v}{\partial a}+u\frac{\partial v}{\partial b}=gu-h\frac{\partial f}{\partial a}-hv\frac{\sqrt{v^2+u^2}}{D^2F}+\alpha\left(\frac{\partial^2 v}{\partial a^2}+\frac{\partial^2 v}{\partial b^2}\right) \tag{7}$$

$$\frac{\partial u}{\partial o}+v\frac{\partial u}{\partial a}+v\frac{\partial u}{\partial b}=-gv-h\frac{\partial f}{\partial b}-hu\frac{\sqrt{v^2+u^2}}{D^2F}+\alpha\left(\frac{\partial^2 v}{\partial a^2}+\frac{\partial^2 v}{\partial b^2}\right) \tag{8}$$

It is very troublesome to solve the above equation for the channel flow field of navigable tunnel in steep bay section with irregular boundary, and it is necessary to transform the governing equations in rectangular coordinate system and body-fitted coordinate system. In order to solve the disparity between the length and width of the computational domain, this article constructs the corresponding curvilinear coordinate equation based on the orthogonal curvilinear grid which can fit the curved boundary of the navigable tunnel in steep bay section. This method can adjust the mesh density by changing the mesh spacing, and at the same time, it can keep orthogonality. The following formula gives the formula for generating orthogonal curvilinear grids:

$$D_\varphi^2 x_{\delta\delta}+D_\delta^2 x_{\varphi\varphi}+J\left(a_\delta E+a_\varphi W\right)=0 \tag{9}$$

$$D_\varphi^2 b_{\delta\delta}+D_\delta^2 b_{\varphi\varphi}+J\left(b_\delta E+b_\varphi W\right)=0 \tag{10}$$

Furthermore, this article constructs the zero-equation turbulence model in the plane two-dimensional orthogonal curvilinear coordinates, which is averaged along the water depth in the entrance area of the approach channel of the navigable tunnel in steep bay section. Assuming that the velocity component in *δ* and *φ* directions is represented by *v* and *u*, the water depth is represented by *f*, the water level is represented by *F*, the acceleration of gravity is represented by *h*, the chezy coefficient is represented by *D*, and the stress term is represented by $\varepsilon_{\delta\delta}$, $\varepsilon_{\varphi\varphi}$, $\varepsilon_{\delta\varphi}$ and $\varepsilon_{\varphi\delta}$, the continuity equation and momentum equation in the new coordinate system are given by the following formulas:

$$\frac{\partial f}{\partial o}+\frac{1}{D_\delta D_\varphi}\left[\frac{\partial\left(D_\varphi Fv\right)}{\partial\delta}+\frac{\partial\left(D_\delta Fu\right)}{\partial\varphi}\right] \tag{11}$$

$$\begin{aligned}&\frac{\partial(Fv)}{\partial o}+\frac{1}{D_\delta D_\varphi}\left[\frac{\partial}{\partial\delta}\left(D_\varphi Fvv\right)+\frac{\partial}{\partial\varphi}\left(D_\delta Fuv\right)+Fuv\frac{\partial C_\xi}{\partial\varphi}-Fu^2\frac{\partial D_\varphi}{\partial\delta}\right]\\&=-\frac{hv\sqrt{v^2+u^2}}{D^2}-\frac{hF}{D_\delta}\frac{\partial f}{\partial\delta}\\&+\frac{1}{D_\delta D_\varphi}\left[\frac{\partial}{\partial\delta}\left(C_\varphi\varepsilon_{\delta\delta}\right)+\frac{\partial}{\partial\varphi}\left(D_\delta\varepsilon_{\varphi\delta}\right)+F\varepsilon_{\varphi\delta}\frac{\partial D_\delta}{\partial\varphi}-F\varepsilon_{\varphi\varphi}\frac{\partial D_\varphi}{\partial\delta}\right]\end{aligned} \tag{12}$$

$$\begin{aligned}&\frac{\partial(Fu)}{\partial o}+\frac{1}{D_\delta D_\varphi}\left[\frac{\partial}{\partial\delta}\left(D_\delta Fvu\right)+\frac{\partial}{\partial\delta}\left(D_\delta Fuu\right)+Fvu\frac{\partial D_\delta}{\partial\varphi}-Fv^2\frac{\partial D_\varphi}{\partial\delta}\right]\\&=-\frac{hv\sqrt{v^2+u^2}}{D^2}-\frac{hF}{D_\delta}\frac{\partial f}{\partial\delta}\\&+\frac{1}{D_\delta D_\varphi}\left[\frac{\partial}{\partial\delta}\left(D_\varphi\varepsilon_{\delta\varphi}\right)+\frac{\partial}{\partial\varphi}\left(D_\delta\varepsilon_{\varphi\varphi}\right)+F\varepsilon_{\varphi\delta}\frac{\partial D_\varphi}{\partial\delta}-H\varepsilon_{\delta\delta}\frac{\partial D_\delta}{\partial\varphi}\right]\end{aligned} \tag{13}$$

It is assumed that the turbulent viscosity coefficient is expressed by *α*, which *α*=*βv*∗*f*, *v*∗=(*hfj*)$^{1/2}$, the expressions of stress terms are as follows:

$$\begin{aligned}&\varepsilon_{\delta\delta}==2\alpha\left[\frac{1}{D_\delta}\frac{\partial u}{\partial\delta}+\frac{u}{D_\delta D_\varphi}\frac{\partial D_\delta}{\partial\varphi}\right]\\&\varepsilon_{\varphi\varphi}==2\alpha\left[\frac{1}{D_\delta}\frac{\partial u}{\partial\varphi}+\frac{v}{D_\delta D_\varphi}\frac{\partial D_\varphi}{\partial\delta}\right]\\&\varepsilon_{\delta\varphi}=\varepsilon_{\varphi\delta}=\alpha\left[\frac{D_\varphi}{D_\delta}\frac{\partial}{\partial\delta}\left(\frac{u}{D_\delta}\right)+\frac{D_\delta}{D_\varphi}\frac{\partial}{\partial\varphi}\left(\frac{v}{D_\delta}\right)\right]\end{aligned} \tag{14}$$

4. STUDY ON NAVIGATION SCHEME OF NAVIGABLE TUNNEL

In order to improve the flow conditions of the navigable tunnel in the steep bay section under large discharge, this article makes an exploratory study on the navigation scheme of the large cross-section navigable tunnel, so as to obtain effective measures to improve the navigation conditions of this section.

According to the proposed initial navigation scheme of navigable tunnel, the flow capacity at the entrance area of approach channel of navigable tunnel in steep bay section of navigable tunnel can be calculated based on the following formula to measure the economy and feasibility of the scheme. Assuming that the head loss coefficient along the route is represented by *μ*, the inner diameter of the navigable tunnel is represented by *c*, the length of the navigable tunnel is represented by *k*, the water passing area of the navigable tunnel is represented by *X*, the sum of the local head loss coefficients is represented by ∑*δ*, and the head difference between inlet and entrance is represented by c_0, then:

$$W=\frac{1}{\sqrt{1+\mu\frac{1}{c}\sum\delta}}X\sqrt{2hc_0} \tag{15}$$

In the navigation scheme of navigable tunnel, there are 5000*t*, 8000*t* and 10000*t* cargo ships preset for the navigable tunnel with dimensions of 110 × 16.3 × 4.3, 130 × 19.2 × 5.5 and 110 × 22 × 5.5 (m) respectively. Assuming that the maximum length of the preset ship type is K_d, the minimum bending radius *S* of the navigable tunnel in the sharp bay section can be calculated as follows:

$$S \geq 5K_d \tag{16}$$

It is assumed that the lowest navigable water level in the navigable scheme of the navigable tunnel is represented by Y_0, the maximum width of the preset ship type is y_d, the total width of ships waiting to pass the gate is represented by y_{d1}, the superwidth between ships is represented by Δy_1, set $\Delta y_1 = y_d$, and the superwidth between ships and shore is represented by Δy_2, taking $\triangle y_2 = 0.5y_d$. The width of the straight line section in the entrance area of the approach channel of the navigable tunnel can be taken according to the following standards:

$$Y_0 \geq y_d + y_{d1} + \Delta y_1 + \Delta y_2 \tag{17}$$

The calculation formula of curve widening is as follows:

$$\Delta Y = \frac{K_d^2}{2S + Y_0} \tag{18}$$

It is assumed that the minimum water depth in the bottom width of approach channel is represented by F_0 and the designed maximum full-load draft of ship is represented by O at the lowest navigable water level in the navigation scheme of navigable tunnel. The minimum water depth of navigable tunnel can be calculated by the following formula:

$$\frac{F_0}{O} \geq 1.5 \tag{19}$$

During the experiment of mathematical model and physical model, it is found that the existing navigation scheme of navigable tunnel cannot effectively improve the navigable flow conditions in the entrance area of the approach channel because of the uneven riverbed, sand dunes and deep grooves. In order to achieve ideal navigation conditions, it is necessary to widen the river locally, extend the separation embankment, block the diversion embankment, level the riverbed, or set up local dredging flood discharge channels and build water diversion structures. Schematic diagrams of different schemes are shown in Figure 1.

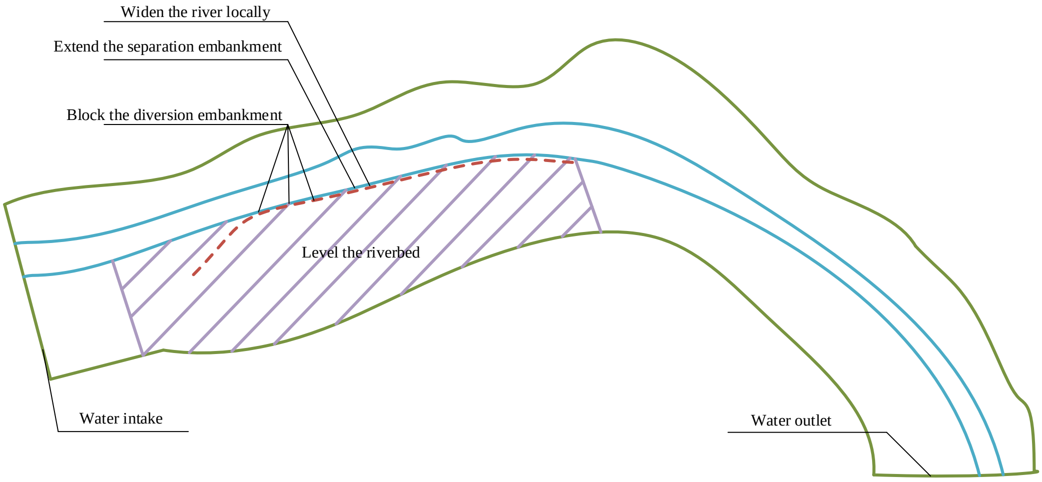


Figure 1. Schematic diagram of different schemes

5. EXPERIMENTAL RESULTS AND ANALYSIS

Based on the medium water flow rate of 6000m^3/s, the analysis and research on the flow conditions of small flow rate below this flow rate or large flow rate above this flow rate have certain reference. Due to the limitation of the study time, this article chooses several navigable tunnels under the conditions of 500m^3/s, 1000m^3/s, 2000m^3/s, 4000m^3/s, 6000m^3/s, 8000m^3/s, 1000m^3/s, 12000m^3/s for test. Table 1 gives the upstream and downstream water level difference of the physical model of navigable tunnel under different discharge levels.

Through adjusting roughness for many times and verifying calculation repeatedly, Table 2 gives the verification results of three level flows such as 2000m^3/s, 6000m^3/s and 12000m^3/s. Through the comparison of water surface line between physical model and mathematical model, it can be found that the water level deviation of the two models is within 0.1 m, which meets the error requirements specified in the *Technical Specification for Flow and Sediment Simulation of Inland Waterway and Port*, and the consistency between water surface line and water surface gradient is high.

Figure 2 and Figure 3 show the verification results of water surface lines and water flow velocities of different sections of navigable tunnel. It can be seen from the figures that the constructed model is in good agreement with the actual situation of the surface flow velocity distribution in the sharp bay section, and the mainstream position and lateral change trend also maintain a good degree of coincidence. The surface velocity deviation of the two models is basically within ± 0.1m, and the maximum is less than 0.2m. It can be verified that the mathematical model and physical model constructed in this article meet the relevant requirements in geometric similarity, flow motion similarity and dynamic similarity.

Table 3 gives a summary of the maximum transverse velocity of each channel section within the entrance area of the approach channel under the physical model. The summary results shows, according to the preset research purpose and physical model experiment requirements, the area from the end of the navigation wall in the entrance area of the approach channel to 400m downstream is the action area of the anti-trajectory-bucket flow pier. In order to ensure that the end of the navigation wall is still affected and sheltered by the anti-trajectory-bucket flow pier, the anti-trajectory-bucket flow pier should be set within the transverse distance of less than 70m from the approach channel. Considering that the section from the end of the navigation wall to its downstream 150m is greatly affected by the discharge flow and the transverse distance between the anti-trajectory-bucket flow pier and the navigation wall, and the cross-flow intensity between the 150m ~ 200m section is the most prominent. Therefore, this article selects 150m section downstream of the end of the navigation wall to carry out the related research on ship navigation trajectory, rudder angle and drift angle.

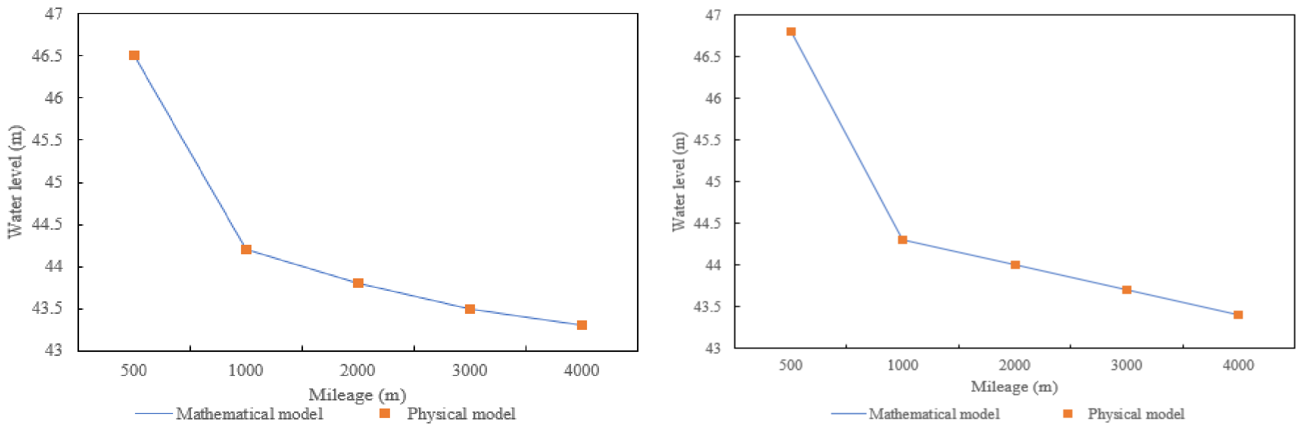
Figure 4 shows the navigation test results of a ship with a section of 150m downstream of the end of the navigation wall and Figure 5 shows the navigation trajectory of the ship. It can be seen from the figures that when the average flow velocity of 150m section is 1.0m/s, the cross flow value of 2.5m of 10000*t* cargo ship with a length of 5m on the route exceeds the limit value. When the ship travels against the current and the speed is about 2.0m/s, the maximum drift angle is -10.54°, and the navigation parameters are not ideal. Only when the navigation speed is increased to over 3.0m/s, the navigation parameters can barely meet the requirements of the threshold value. When the ship travels downstream and the navigation speed is 1.5m/s and 2.0m/s, the maximum rudder angle reaches -22.30° and 21.64°, respectively, and the maximum drift angle reaches 9.67° and 9.96°, respectively. The navigation parameters are not ideal enough to ensure the safe passage of ships through the entrance area of the approach channel. Only when the navigation speed is increased to over 2.5m/s will the navigation parameters meet the requirements of the threshold value.

Table 1. Water level difference between upstream and downstream of navigable tunnel under different discharge levels

SN	Corresponding flow	Upstream reservoir water level	Downstream water level	Water level difference
1	500	93.35	83.34	8.63
2	1000	94.17	84.72	7.82
3	2000	94.58	86.35	7.06
4	4000	96.41	87.52	7.74
5	6000	98.52	88.67	7.17
6	8000	99.27	89.35	7.86
7	10000	100.25	89.41	7.08
8	12000	100.41	90.57	5.88

Table 2. Comparison of water level calculated by mathematical model and physical model

Flow	Water gauge No.	Mileage	Left bank			Right bank		
			Mathematical model	Physical model	Deviation	Mathematical model	Physical model	Deviation
	1	-251	41.629	44.364	-0.058	43.629	43.629	0.093
2000	2	569	49.581	48.572	-0.024	41.528	44.517	-0.041
1000	3	1542	43.629	42.591	0.063	47.152	43.528	-0.027
500	4	3629	41.582	47.514	-0.058	46.295	48.251	-0.015
	Tail water	3471	40.639	43.625	0.041	43.152	47.625	0.016
	1	-258	46.152	46.298	0.029	48.327	41.025	-0.034
6000	2	569	44.281	44.271	0.035	44.051	43.519	0.012
4000	3	1152	47.629	43.581	0.041	43.629	47.642	-0.052
2000	4	3514	43.522	46.295	-0.025	48.527	48.032	-0.069
	Tail water	3629	49.625	42.733	0.041	43.625	41.472	0.025
	1	-254	55.847	51.629	0.017	54.026	53.629	0.018
12000	2	526	53.629	57.428	-0.069	53.629	57.418	0.052
10000	3	1742	51.248	55.382	0.037	55.814	55.014	-0.041
8000	4	3629	57.426	58.629	-0.024	57.324	53.629	-0.069
	Tail water	3274	53.629	56.412	0.025	51.247	57.441	0.035



1)

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Figure 2. Verification of water surface lines of different sections of navigable tunnel

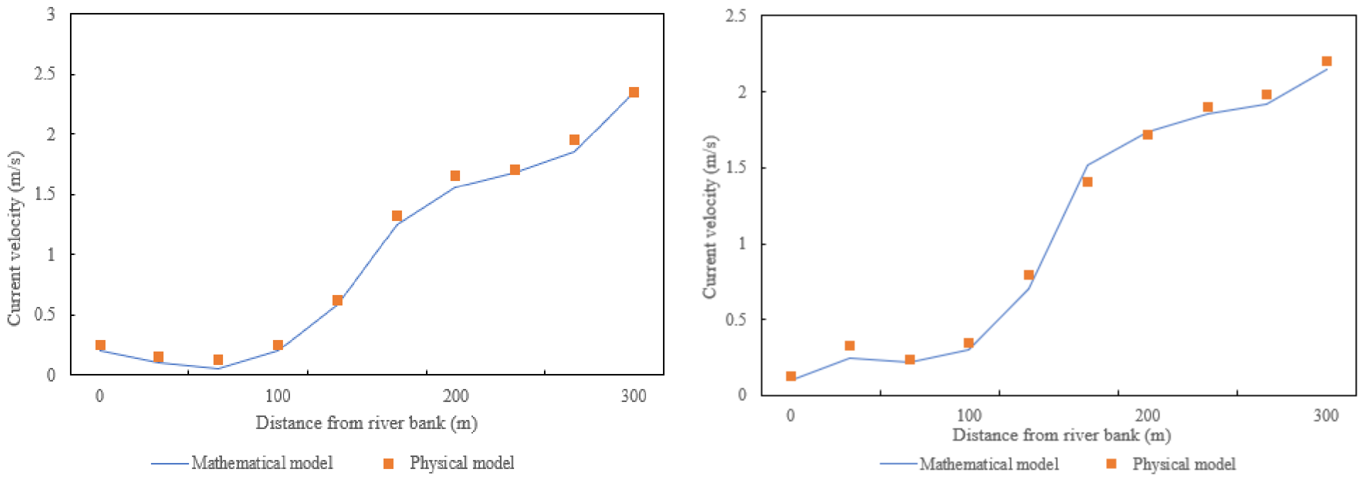

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Figure 3. Verification of flow velocity in different sections of navigable tunnel

Table 3. Maximum transverse velocity of navigable tunnel cross section under different schemes

Transverse distance **Measured cross-sections**	**No trajectory-bucket flow pier**	**20*m***	**30*m***	**40*m***	**50*m***	**60*m***	**70*m***	**80*m***	**90*m***	**100*m***
50*m*	0.52	0.03	0.04	0.01	0.14	0.19	0.01	0.39	0.35	0.42
100*m*	0.53	0.35	0.29	0.24	0.26	0.23	0.29	0.27	0.24	0.26
150*m*	0.41	0.42	0.45	0.34	0.37	0.37	0.37	0.22	0.29	0.27
200*m*	0.34	0.41	0.49	0.45	0.39	0.41	0.34	0.29	0.21	0.29
250*m*	0.39	0.46	0.36	0.39	0.33	0.47	0.31	0.34	0.35	0.24
300*m*	0.25	0.38	0.34	0.31	0.39	0.35	0.39	0.37	0.26	0.26
350*m*	0.21	0.25	0.29	0.27	0.22	0.28	0.24	0.22	0.22	0.28
400*m*	0.15	0.22	0.27	0.24	0.28	0.22	0.21	0.27	0.24	0.22

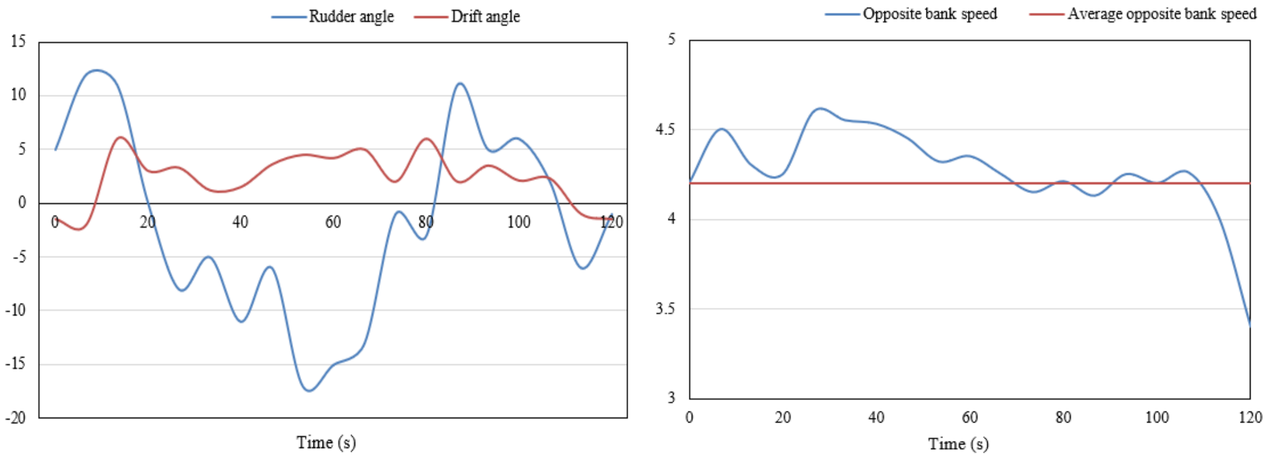

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Figure 4. Rudder angle, drift angle and speed of ship navigation

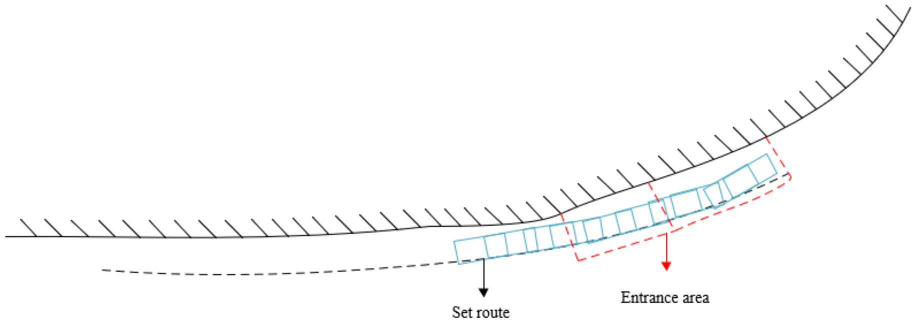

Figure 5. Schematic diagram of ship navigation trajectory

When the average flow velocity of 150m section is 1.5m/s, the cross flow value of 2.75m of 10000*t* cargo ship with a length of 5m on the route exceeds the limit value. The maximum rudder angle is about 23.14° and the maximum drift angle is about -13.11° when the ship travels against the current and the speed is about 3.0m/s, so the navigation parameters are not ideal. Only when the navigation speed is increased to over 3.5m/s, the navigation parameters can barely meet the requirements of the threshold value. When the ship travels downstream at 2.0m/s and 2.5m/s, the maximum rudder angle reaches -22.45° and 21.73°, respectively, and the maximum drift angle reaches 11.23° and 11.92°, respectively. The navigation parameters are not ideal enough to ensure the safe passage of ships through the entrance area of the approach channel. Only when the navigation speed is increased to 3.0 ~ 3.5m/s will the navigation parameters meet the requirements of the threshold value.

6. CONCLUSION

This article studies the characteristics of navigation flow conditions and numerical simulation of water conservancy in steep bay section of the tunnel. Firstly, the physical model of tunnel navigation in steep bay section is designed to ensure the geometric similarity, flow movement similarity and dynamic similarity between the model and the actual situation in steep bay section. Then, the numerical simulation of navigation water conservancy in steep bay section of tunnel is carried out, and the continuity equation and momentum equation in the new coordinate system are given. This article explores the navigation scheme of large cross-section navigable tunnel in order to obtain effective measures to improve the navigation conditions of this section. Finally, by adjusting roughness several times and repeatedly validating calculation, this article obtains the validation results of three level flow rate such as 2000m^3/s, 6000m^3/s and 12000m^3/s, which verifies the effectiveness of the physical model and mathematical model. It obtains the verification results of water surface lines and water flow velocities of different sections of navigable tunnels and further verifies that the mathematical model and physical model constructed have reached the relevant requirements in geometric similarity, flow motion similarity and dynamic similarity. It summarizes the maximum transverse velocity of each channel section in the entrance area of approach channel under the physical model, selects the section 150m downstream of the end of the navigation wall to study the ship's navigation trajectory, rudder angle and drift angle, and obtains the corresponding research results.

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