NUMERICAL SIMULATION ON NAVIGATION CONDITION IN THE RIVER REACH BETWEEN THREE-GORGES PROJECT AND GEZHOUBA PROJECT

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ABSTRACT

In this paper **a** numerical model is built which combines a two-dimensional river model and a ship maneuvering mathematical model. By the model, the river flow conditions between Three-Gorges Project and Gezhouba Project are studied. The navigation conditions on the rapids in the reach are analyzed, and the track lines for six ships transit the rapids are also simulated. The parameters of navigation in the sail course are obtained. The safe discharges that typical ships transit the reach are ascertained by synthesizing analyses of the data.

1. INTRODUCTION

The 38km river reach between Three-Gorges Project and Gezhouba Project is one of the well-known navigation hindering reaches in the uppper Yangtze River, and it is a most difficult reach to sail for vessels too. After the completion of Gezhouba dam, this reach is of the permanent backwater zone (see Fig. 1), flowing gently in the medium-low flow period, with smaller velocity

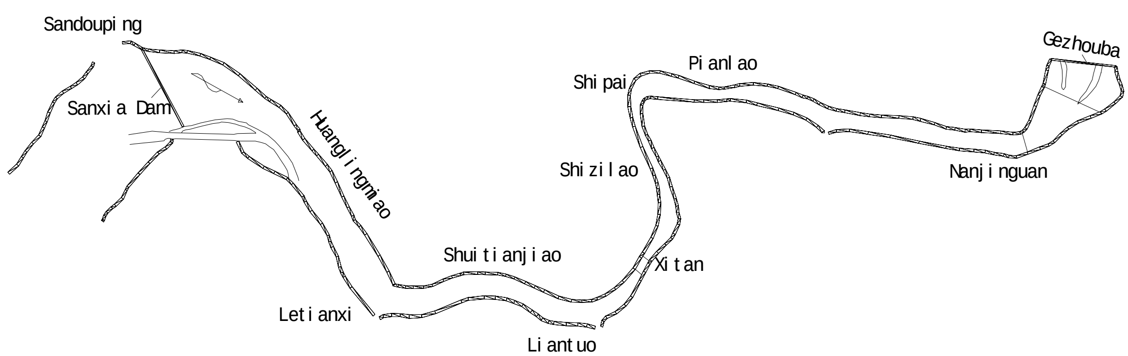

Fig. 1 Layout of shoals between Three-Gorges Project and Gezhouba Project

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and gradient, and flowing fast in the flood season due to deep channel and steep valley. There are a lot of navigation hindering shoals such as Xitan, Shuitianjiao, Shipai, Shizinao, Piannao and so on, which are well-known flood-induced shoals. It is important for ships and fleets to determine navigable discharges flowing along this reach, because various kinds of vessels passing through this reach have different powers and propulsive forces. So it is necessary for representative ships and fleets to study navigation conditions and rapids-ascending ability of ships, by use of a two-dimensional flow model and a ship maneuvering model, so as to determine navigable discharges suitable for ship sailing under existing conditions.

2. MATHEMATICAL MODEL FOR FLOW

2.1 Basic equations

The two-dimensional flow movement is described by a closed system of shallow water equations averaged along the water depth:

(1) Continuity equation

$$\frac{\partial h}{\partial t}+\frac{\partial}{\partial x}(hu)+\frac{\partial}{\partial y}(hv)=0 \tag{1}$$

(2) Momentum equation along X-direction

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+g\left(\frac{\partial h}{\partial x}+\frac{\partial a}{\partial x}\right)-\frac{\varepsilon_{xx}}{\rho}\frac{\partial^2 u}{\partial x^2}-\frac{\varepsilon_{xy}}{\rho}\frac{\partial^2 u}{\partial y^2}+\frac{u\sqrt{u^2+v^2}n^2 g}{h^{4/3}}=0 \tag{2}$$

(3) Momentum equation along Y-direction

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+g\left(\frac{\partial h}{\partial y}+\frac{\partial a}{\partial y}\right)-\frac{\varepsilon_{xy}}{\rho}\frac{\partial^2 v}{\partial x^2}-\frac{\varepsilon_{yy}}{\rho}\frac{\partial^2 v}{\partial y^2}+\frac{v\sqrt{u^2+v^2}n^2 g}{h^{4/3}}=0 \tag{3}$$

Where t - time; u、v – the velocities along the X、Y directions; h – the water depth; η **- the** bed elevation; g – the acceleration of gravity; ε_{xx}、ε_{yy}、ε_{xy} -the turbulent viscosity coefficients，taking $\alpha u_* h$， $\alpha = 3 \sim 5$， n - the roughness coefficient; u_* - the friction velocities。

Discretization of shallow water equations includes time and space dispersions. And the finite difference method is used in time dispersion and the finite element method used in space dispersion. By use of Galerkin weighted residual method, the shallow water equations are dispersed as non-linear algebraic equation and then solved by Newton-Raphson method. And within discrete intervals is used a coupling of isoparametric elements having triangle with six nodes and quadrangle with eight nodes.

2.2 Calculation grid

Upon an essential consideration of a long reach between two dams, Gezhouba and the Three-Gorges, the combination of one-dimensional and two-dimensional numerical models is used, that is the one-dimensional model provides boundary conditions for the two-dimensional model which is used for estimating flow conditions of the shoals. And navigation parameters and track lines of the vessels (fleets) are estimated on the bases of the numerical model. Figure 2 shows a grid chart of Shuitianjiao rapids.

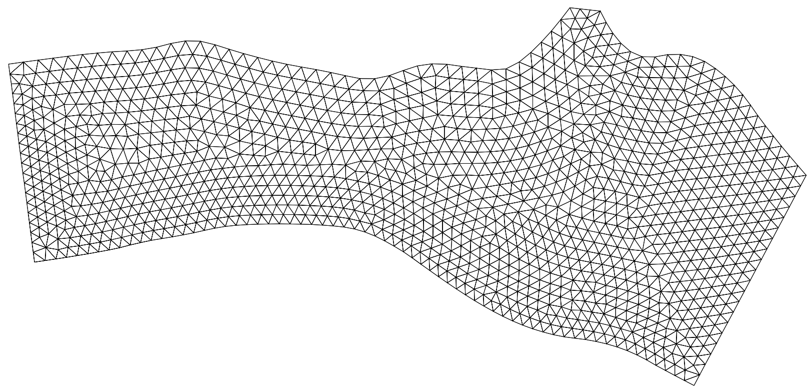
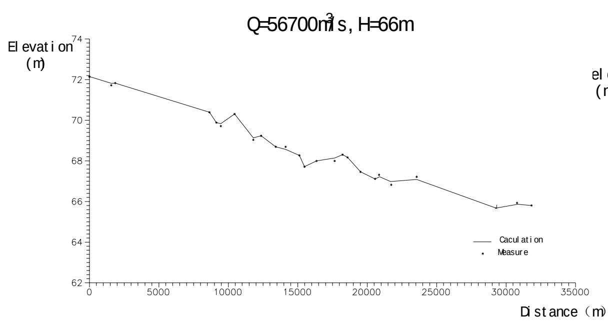


Fig. 2 Grid chart of Shuitianjiao shoal

2.3 Model verification

Comparison of the measured water levels between the mathematical and physical models is carried out in the study, and the water-levels at Nanjinguan，Piannao，Xitan, Shuitianjiao, Shipai, Shizinao, Doushantu，Letianxi are verified during model verification tests. It is shown from the verification results that there is little difference between the measured and calculated water level obtained from the physical models. The range of stage between two water levels is less than 10cm, except that a few is greater(about 15-20cm). figure 3 shows the verified results of water levels under conditions of 56700m³/s discharge and 66m water level in front of Gezhouba dam.

Velocities and water levels are simultaneously verified. For Piannao，Shipai, Shizinao, Xitan, and Shuitianjiao shoals the velocity verification tests and calculation are carried out in the model study. The figure 3 shows the verified results of velocities of Shuitianjiao section under conditions of 35000m³/s discharge and 63m water level in front of Gezhouba dam. The results show there is a small difference between the calculated and measured velocities at various points, in general, less than 0.10m/s, except that a few is slightly greater than(0.15-0.25m/s). And the relative errors are not exceeding ±10%. The verification outcom shows that the calculated results well conform with the measured data from the physical model.



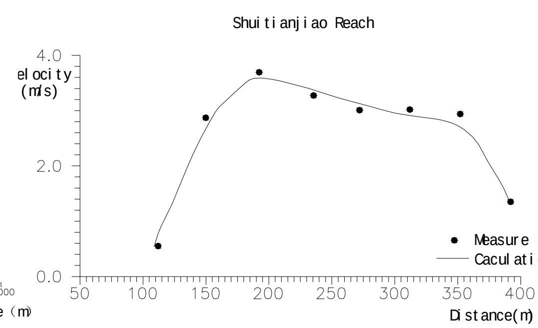


Fig. 3 Verification of water level Fig. 4 Verification of velocity

2.4 Mathematical model for ship maneuvering

2.4.1 Basic equations

Ship maneuvering on waters can be taken as a collateral action of bow-stern and abeam directions as well as turning motion moving round the longitudinal center of gravity, that is to say the maneuvering can be taken as a composite motion of ahead, lateral shift with turning. Evidently this relationship between maneuvering and acting force can be described by Newton's second law. From this it is easy to give the following equations of the ship maneuvering:

$$
\begin{aligned}
(I_z + I_{zz})\dot{\gamma} &= N \\
(m + m_x)\dot{v}_x - (m + m_y)v_y\dot{\gamma} &= X \\
(m + m_y)\dot{v}_y - (m + m_x)v_x\dot{\gamma} &= Y
\end{aligned} \tag{4}
$$

In which γ - the velocity of turning angle； X、Y- the velocity component of ship in the bow-stern and transverse directions； m_x、m_y、I_z – the added mass and added moment of inertia in x and y directions； Solving Eq.(4), it yields the right term, that means an expression for force is most important. From analysis of a given force relationship it can be shown that the force consists of three forces: the first is a current-induced force, the second is a force induced by the ship maneuvering and the third is an outside acting force (such as wind and wave, etc.). Thus it can be seen that solving problems of ship maneuvering, the waterway flow conditions must be first understood, and then some operation parameters would be given for steering, ship handling/dispatching, etc. Again, analyzing force acting on ships, it can solve Eq.(4) and finally the ship motion procedure would be given on the bases of these analyses. Forces and moments produced by the bare hull, helm, propeller as well as wind and wave are respectively calculated by hydrodynamic method in this model study.

2.4.2 Solutions of equations for the ship motion

Dispersing Eq.(4), the ship motion at whatever time can be solved by successive integration of discrete equations. If taking sailing velocity against banks as an absolute velocity, thus the ship motion against current can be considered as a relative motion and the velocity against current can be considered as a relative velocity. After dispersing equation for ship motion against current, the parameters for ship motion against banks can be obtained.

(1) Motion against current

$$\dot{v}_{xi} = \frac{X_i}{m + m_x}$$

$$\dot{v}_{yi} = \frac{(I_z + I_{zz})Y_i + Y_i N_i}{(m + m_y)(I_z + I_{zz}) - Y_i N_i}$$

$$\dot{\gamma}_i = \frac{(m + m_y)N_i + N_i Y_i}{(m + m_y)(I_z + I_{zz}) - Y_i N_i}$$

$$X_i = X_{Hi} + X_{Ri} + X_{\rho i} + X_{Wi} + X_{Wvi} + (m + m_y)v_{yi}\gamma_i \quad Y_i = Y_{Hi} + Y_{Ri} + Y_{\rho i} + Y_{Wi} + N_{Wvi} - (m + m_x)v_{yi}\gamma_i$$

$$N_i = N_{Hi} + N_{Ri} + N_{\rho i} + N_{Wi} + N_{Wvi}$$

$$v_{x,i+1} = v_{xi} + \dot{v}_{xi}\Delta t$$

$$v_{y,i+1} = v_{yi} + \dot{v}_{yi}\Delta t$$

$$x'_{i+1} = x'_i + (v_{xi} \cos\varphi_i - v_{yi} \sin\varphi_i)\Delta t$$

$$y'_{i+1} = y'_i + (v_{xi} \sin\varphi_i + v_{yi} \cos\varphi_i)\Delta t$$

$$\varphi_{i+1} = \varphi_i + \gamma_i \Delta t$$

where x'、y'- the hull barycentre coordinates (against current), φ- the forward/bow angle, γ_i- the velocity of swing angle, v_x、v_y-the velocity component of ship motion against current in *x* and *y* directions, and the the other symbols are same as those mentioned above.

(2) Motion against banks

Based on the calculation of motion against current, the navigation parameters for ship motion against banks can be further estimated, by the following equations:

$$x_{i+1} = x_i + (u_{xi} \cos\varphi_i - u_{yi} \sin\varphi_i)\Delta t$$

$$u_{x,i+1} = v_{x,i+1} - v_F \cos(\psi_F - \varphi_{i+1})$$

$$u_{y,i+1} = v_{y,i+1} - v_F \sin(\psi_F - \varphi_{i+1})$$

$$Y_{i+1} = Y_i + (u_{xi} \sin\varphi_i + u_{yi} \cos\varphi_i)\Delta t$$

3. ANALYSES OF THE CALCULATED RESULTS

3.1 Flow conditions

Using the above mentioned models, 10 groups of flow condition tests are calculated respectively under conditions of discharges of 25000，35000，40000，45000，56700m^3/s and water levels of 63, 66m at Gezhouba dam. Figure 5 shows isovel distribution along Shuitianjiao shoal under the condition of discharge of 40000m^3/s. From analyses of the maximum vertical average velocities under conditions of various discharges it can be found that these average velocities are high with the increase in discharge and would be of approximate linear relationship. At the same time it can be seen that the rise of downstream stage has no great effect on the maximum velocities at Xitan and Shuitianjiao, only with a small change. And from statistics of the maximum velocities along the planed navigation line it is also found when the discharge is 40000m^3/s or lower, all maximum velocities of shoals are less than 4.0m/s, and when the discharge is 40000m^3/s or larger, the maximum velocities of shoals are 3.55～5.20m/s. Judging by velocities along the navigation line, the velocity at Shuitianjiao is found to be the greatest, which become a control reach among various shoals.

3.2 Calculation and analyses of ship sailing

Numerical simulation for ship sailing is carried out on the bases of the calculated results of flow. The navigation parameters of 6 representative ships and fleets have been estimated and their data is shown in Table1.

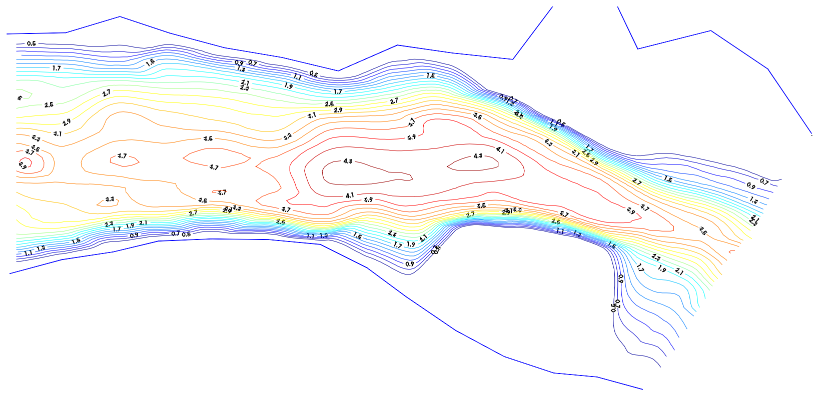


Fig.5 Isovels at Shuitianjiao

Table 1 Calculated representative ships

Calculated representative ships	L×W×Draft （m×m×m）	Sailing speed （km/h）	Propeller power (kw)
1200kw+4×800T Fleet	174.3×22.1×2.3	15	1200
2000T Bulk carrier	84.9×14.0×2.8	18	2×358
486KW＋3×500T Fleet	126×20.1×1.8	12	486
210TEU Container carrier	89.9×14.6×3.4	20	430×2
1500T Self-propeller ship	69.5×12×3.1	18	440
700 T Self-propeller ship	57×10.2×2.4	16	270

The 60 groups ship sailing courses are simulated when discharge are 25000，35000，40000，45000，56700m^3/s and water levels of 63, 66m at Gezhouba dam. The calculated results show that all the minimum sailing speed against banks occur along Shuitianjiao shoal, and the maximum drift angle along Shipai shoal. This means that Shuitianjiao shoal has become a difficult point obstructing upbound ships and Shipai shoal has become a difficult point obstructing downbound ships passing through two dams (Gezhouba and the Three-Gorges dams). Based on the calculated results, the sailing speed against banks must be less than 0.4m/s and the maximum helm angle must not be over 25º. Some statistics on safe navigation standards for ships have been made and Table 2 listed safe

Table 2 Safe navigation discharges of the representative ships

Representative ships	Safe navigation discharges Q (m^3/s)
1200kw+4×800T	Q≤35000
2000T Bulk carrier	Q≤45000
486KW＋3×500T	Q≤25000
1500 T Self-propeller ship	Q≤45000
700 T Self-propeller ship	Q≤45000
210TEU Container carrier	Q≤45000

navigation discharges of the representative ships passing through two dams. These research findings have been applied to navigable management of Gezhouba and the Three-Gorges. Figures 6-7 show the navigation parameters and track lines of upbound 1200kw+4×800T fleets passing through Shuitianjiao shoal.

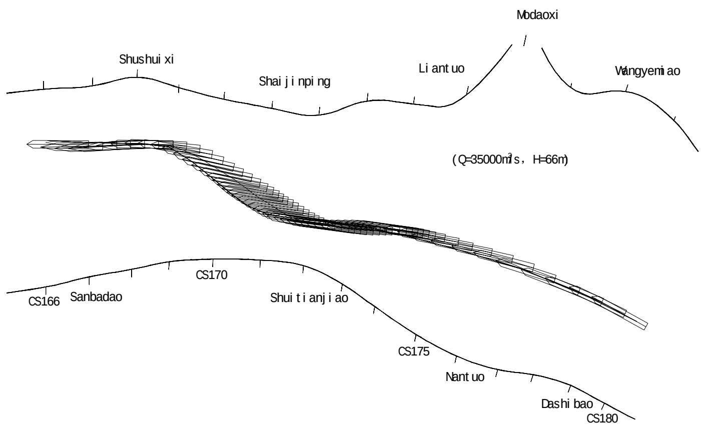


Fig. 6 Track lines

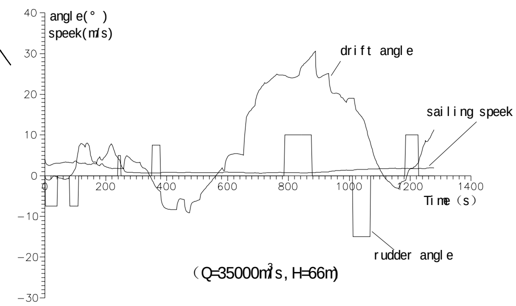


Fig.7 Navigation parameters

4. CONCLUSIONS

The mathematical model well simulated complex channel boundary and the simulated results well conforms with the measured dada. The river flow conditions between Three-Gorges Project and Gezhouba Project are studied. The navigation conditions on the rapids in the reach are analyzed, and the track lines for six typical ships transit the rapids are also simulated. The parameters of navigation in the sail course are obtained. And the safe navigation discharges of 6 representative ships passing through Gezhouba and the Three-Gorges dams have been obtained from analyses and calculation.

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