A numerical simulation study on the sedimentation dredging in Lushui Reservoir, part 1: model building and validation

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Abstract. Based on the characteristics of the river regime, sediment deposition and the distribution of hydrological stations in Lushui reservoir, a depth-averaged two-dimensional flow mathematical model is established in this paper. Then based on the filed data observed at the hydrological station networks in the reservoir, the mathematical model was verified and calculated. The validation simulation results show that the mathematical model can well reflect the flow movement in the studied reach, and this will provide a good technical support for the influence of sedimentation dredging in the reservoir area.

1. Introduction

The sedimentation dredging in reservoir inevitably will bring the disturbance to the river flow where the dredging is located. As a result, the study on its impact is essential in the process of project implementation. At present, as an important technical means to study the flow movement, mathematical model plays an increasingly important role in river regulation, flood control, navigation and other water conservancy construction. Compared with the physical model experiment, it has the advantages of fast calculation speed, high simulation accuracy and low economic cost. Therefore, this paper establishes a two-dimensional flow mathematical model of Lushui reservoir, and uses the data of hydrological stations in the reservoir to verify the mathematical model. The verified model can provide a good technical support for the analysis of the influence of reservoir dredging.

2. Data and model

2.1. Study area and data

Lushui Reservoir is a large-scale experimental reservoir of Three Gorges, Gezhouba and other reservoirs, which has made outstanding contributions to the development history of water conservancy and hydropower in China. Considering the river regime, research content, hydrological data and other factors, the section of about 25km from Yanggang bridge to Houwangmiao was selected as the calculation and analysis reach, as shown in figure 1.

Before the impoundment of Lushui reservoir, a permanent hydrological station network, shown in figure 2, had been set up in the reservoir area for the operation observation after the built of the reservoir. In this paper, the two-dimensional mathematical model is verified by selecting the water level and flow data of the hydrological station network during the flood period from June 24 to July 28, 2017. During the observation period, the maximum inflow flow is 2218m3/s, the minimum inflow flow is 36m3/s, the maximum boundary water level is 52.5m, and the minimum is 49.5m.
2.2. 2D mathematic model

2.2.1. Governing equations. In this paper, the two-dimensional mathematical model was used for the numerical simulation study on the sedimentation dredging in Lushui Reservoir. The mathematical model adopts the plane two-dimensional flow equations in the orthogonal curvilinear coordinate system \cite{4}:

\[ \frac{\partial (C_z H U)}{\partial t} + \frac{\partial (C_z H V)}{\partial \eta} = 0 \]  

\[ \frac{\partial (C_z H U)}{\partial t} + \frac{\partial (C_z H V)}{\partial \eta} + \frac{\partial^2 (C_z H U)}{\partial \xi^2} - \frac{\partial (C_z H U)}{\partial \eta} - H \frac{\partial (C_z H V)}{\partial \eta} + C_g H \frac{\partial Z}{\partial \xi} = \]  

\[ - \frac{C_z n^2 g U^2 V^2}{H^2} + C_z n^2 g H U V + \frac{\partial}{\partial \eta} \left( C_z H \sigma_{\eta \eta} \right) + \frac{\partial}{\partial \xi} \left( C_z H \sigma_{\xi \xi} \right) + H \sigma_{\eta \eta} \frac{\partial Z}{\partial \eta} - \sigma_{\xi \eta} \frac{\partial Z}{\partial \xi} \]  

Where, \( U \) and \( V \) are velocity components in \( \xi \) and \( \eta \) directions respectively; \( Z \) is water level; \( H \) is water depth; \( g \) is acceleration of gravity; \( \sigma_{\xi \xi}, \sigma_{\eta \eta}, \sigma_{\xi \eta} \) and \( \sigma_{\eta \xi} \) are stress terms; \( \nu_t \) is turbulent viscosity coefficient, and \( f \) is Coriolis force coefficient.
To solve the differential equation, the finite volume method\cite{5} is used for the numerical discretization of the equation (1) ~ equation (3), and the simple algorithm is used for the solution of the discrete equation\cite{6}. In the process of solving, the Gauss Seidel iteration is used as the main iteration algorithm, and the over relaxation and under relaxation techniques are used.

Figure 2. Map of the study reach in Lushui Reservoir.  
Figure 3. Map of the grid for the two-dimensional mathematical model.

2.2.2. Key problems and solutions. (1) calculation grid. The calculation grid adopts the form of body fitted curve grid on the river boundary\cite{7}. The length of the calculated river section is about 25km, the number of grid nodes is 400 × 150, the spacing in water flow direction grid is 60-200m, and the spacing in vertical water flow direction grid is 5-80m. The grad is shown in figure 3. (2) Moving boundary treatment. The dynamic boundary problem of numerical simulation is mainly caused by the change of water level and iterative calculation. The following dynamic boundary simulation techniques are adopted: the calculation nodes of water area and land area are distinguished according to the water depth value of each calculation; the calculation nodes of the bank boundary are treated by the boundary partition method; the calculation nodes of the bank boundary keep a small surplus water depth ($H_{\text{min}} = 0.001\text{m}$), so that the calculation can proceed; the water level of the land area is extended by the water level of the near shore area. (3) Coefficient of roughness. In fact, the roughness coefficient used in the mathematical model calculation is a comprehensive coefficient, which reflects many factors such as the flow resistance of the river, the change of the plane shape of the river, the generalization of the river topography, etc. However, the measured data of the roughness of the natural river channel is relatively lacking. Therefore, the calculation of the roughness in the river reach is generally based on the measured
hydrological data, and according to the local topography, commissioning is carried out in blocks. The turbulent viscosity coefficient $v_t$ is related to the turbulent stress in the flow, which is determined by the turbulence model. In general, in order to simplify the calculation, the constant coefficient equation is usually used to solve the problem. The empirical relationship is $v_t = C u^* h$, and $C$ is the empirical constant (ranging from 0.25 to 1.0). In this calculation, $C$ is 1.0.

3. Results and discussion

3.1. Water level validation

Figure 4 has given the diagram of water level verification results for the 6 hydrological stations. It can be seen from the figure 3 that the calculated water level of each station along the route was basically the same as the measured water level, and the maximum absolute error value was about 0.01m, which was in good agreement with the measured value.

3.2. Flow velocity validation

Figure 5 has given two maps of the flow velocity distribution during the verification calculation. It can be seen from the figure 4 that the main flow of the calculation is clear and the beach channel is clearly distinguished, which conforms to the general law of water flow movement.

In general, the calculation results of the mathematical model are in good agreement with the measured results, which can be used to analyse the influence of dredging on the flow.
Figure 5. Maps of the flow distribution for verification calculation.

4. Conclusions
The 2D mathematic model with vertical averaged flow was built for the Lushui Reservoir. By using a series of field data, the validation of the model was carried out. The result shows that the model can well reflect the water flow movement in this study reach, both for the water level and flow velocity. This will provide a good way to analyse the influence of dredging on the flow in Lushui Reservoir.

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