Influence of parameters valuing on calculation results in reservoir sediment mathematical model

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Abstract. Sediment deposition in the reservoir not only has a serious impact on the service life of the reservoir and the existence value of the hydropower station, but also profoundly affects the erosion and siltation of the downstream riverbed and the safety of the dam. Being an important method to the research of sedimentation problem, calculation accuracy of mathematical model is a subject worthy of continuous discussion. In this paper, influence of some key parameters of the model are analysed. The calculation results show that the changes of dry density, water flow sedimentation parameters and saturation recovery coefficient have significant influence on the calculation results, and the change of dry density has the greatest influence, while the effect of flocculation is the weakest. It is worth noting that when considering these influencing factors, this paper adopts a simplified processing method, and the mechanism of each parameter is complex, and further research is needed.

1. Introduction
After the construction of reservoirs on the river, due to the elevation of water level and reduction of the flow velocity, a huge number of sediment from the upstream is silted into the reservoir, which is a direct threat to the service life of the reservoir and the safety of the dam. To reduce the impact of the reservoir sediment deposition, and fully bring out the comprehensive benefits of the reservoir, it’s necessary to carry out quantitative analysis on reservoirs silting. Over the years, China has accomplished a lot of work on reservoir siltation [1], mainly through measured data analysis, flume experiment, and physical and mathematical modelling.

This paper mainly focuses on the calculation accuracy issue of mathematical models. In previous work, the author studied the siltation of Yantan Reservoir, and adjusted the relevant calculation parameters in the model by comparing with the measured data, and improved the calculation results of the model. The calculation results of sedimentation in the reservoir area are close to the measured values [2]. Based on the preliminary work, this paper takes Yantan Reservoir as an example to study and analyze the influence of various parameters in the reservoir water sediment mathematical model on the calculation results.

2. Analysis of Related Parameters in Reservoir Sediment Mathematical Model
The calculation accuracy of the one-dimensional mathematical model is closely related to the valuing of the parameters in the function. The parameters that need to be analysed mainly consists of dry
density, water flow sediment-carrying force factor, saturation recovery coefficient, roughness and flocculation. The mechanism of each influencing parameter is as follows.

(1) Influence of dry density
The dry density of reservoir sediments varies widely. It affects the conversion of silt weight and volume, the variation of silt volume after compaction of fine-grained sediments, and the variation of sediment starting velocity and sediment-carrying capacity. It is an important parameter for reservoir siltation calculation, and needs to be carefully chosen\(^1\). Some existing studies have shown that: the dry density of sediment in the reservoir area increases along with the increasing of the particle size, and the initial dry density of the fine-grained sediment (the initial dry density refers to the dry bulk density during the initial stabilization of the sediment at the begging of siltation). When \(d\) is between 0.005 to 0.010 mm, the value of dry density adopts \(778 \text{ kg/m}^3\)\(^1\). If the sedimentation period is very long, usually stabilized dry density (the dry bulk density of the sludge after long-term compaction) is directly adopted. According to Han Qiwei et al.\(^1\), when \(d\) is between 0.005 to 0.010mm, the dry density adopts 1000~1300kg/m\(^3\).

(2) Influence of sediment carrying force factor
The calculation of sediment carrying force is key module of the sediment mathematical model, whose calculation accuracy directly affects the suspended sediment concentration and riverbed deformation amplitude. The formula of Zhang Ruiqi is adopted to calculate the water flow sediment carrying force in this paper. The formula is as follows:

\[
mgh \left( \frac{U}{\omega} \right)^k \]

Where: \(K\), \(m\) are the coefficient and index of sediment carrying force of flow, \(U\) and \(h\) are the average flow velocity and average water depth of the section, respectively, and \(g\) is the acceleration of gravity, \(\omega\) is the sedimentation speed of the particle.

In the formula of water flow and sedimentation proposed by Zhang Ruiqi et al.\(^1\), \(K\) and \(m\) are hard to determine, and need to be calibrated by site measuring. Therefore, the parameters used in the calculation of the mathematical sediment model varies in each project. For example, according to the results of the Gongzui station data, \(K=0.124\), \(m=1.05\), however, according to water tank experiment result by Liu Jianjun et al.\(^3\), According to the results of the flume experiment, the parameters of the suspended sediments on the Hongshui River where the Yantan Reservoir are located, it’s more reasonable to adopt 0.185 and 0.666 for \(K\) and \(m\).

(3) Influence of saturation coefficient
The saturation recovery coefficient is an important parameter reflecting the recovery rate of sediment concentration towards saturated sediment concentration, or sediment carrying capacity during unbalanced sediment transportation. Saturation recovery coefficient directly affects the amount of riverbed erosion and siltation, which has an important impact on the calculation of sediment erosion and deposition \(^4\). Some scholars have studied the valuing of the saturation recovery coefficient \(^5-8\), and basically have the following consensus: ① Different particle size groups have different saturation recovery coefficient. ② Value of saturation recovery coefficients decrease as the sediment particle size increase, ③ Value of saturation recovery coefficient varies with space and time. In the one-dimensional water and sediment model, empirical results are generally used, that is, the saturation recovery coefficient of sediment is 0.25. When flushing, the saturation recovery coefficient of sediment is 1.0 \(^1\). The greater the saturation recovery coefficient is, the greater the ratio of sediment concentration along the river is, and the faster the sediment concentration recovers to the sediment carrying capacity.

(4) Influence of fine particle sediment flocculation
Finer viscous particles will condense together in the water, and flocculation will occur, which will affect sediment transport and sedimentation to some extent. Sediment particle size is one of the important factors affecting flocculation. In a specific water environment, only sediment particles below the threshold particle size will flocculate \(^9\). In addition, according to Wang Dangwei et al.\(^10\),
fine-grained sediment provides the basic conditions for flocculation, but whether it will flocculate also closely relates to the water environment factors, especially to the species and concentration of ions in the water. For the convenience of model calculation, this paper only considers the influence of sediment particle size on flocculation.

(5) Influence of roughness

The influence of water flow friction in the one-dimensional mathematical model is usually reflected by the roughness (n). The rougher the boundary surface of the river, the greater the roughness; the smoother the boundary surface, the smaller the roughness. In the modelling, it is usually obtained through the measured values of the river section or referring to similar engineering experience. In this paper, the value of roughness is determined by the site measurement in the reservoir area.

3. Introduction to the preliminary calculation results of Yantan Reservoir

(1) Model introduction

The sedimentation and siltation calculation of Yantan Reservoir adopts the one-dimensional constant non-uniform unbalanced sediment transport mathematical model “SUSBED-2” developed by Yang Guolu and Wu Weimin [11]. This model has been widely promoted in domestic design institutes, and widely used in the research and design of water conservancy and hydropower projects in small and medium rivers [11].

Yantan Reservoir locates on the Hongshui River, which is the upper reaches of the Xijiang River in Guangxi Province. The calculated river section in the model ranges from the dam site of Yantan Hydropower Station to the upper bank of Longtan Hydropower Station upstream, with a total length of 166.6km. SUSBED-2 is adopted to recalculate the water and series of Yantan Reservoir from April 1994 to December 1999. The calculation results are detailed in the reference [2].

(2) Value of relevant parameters

The relevant parameters in the modelling are obtained based on the measured data of the watershed the Yantan Reservoir locates and with reference to similar engineering experience. The values of the calculated parameters are as follows: the dry density is 800 kg/m\(^3\); the saturation recovery coefficient of the suspended sediment is 0.7; the coefficient and index of the suspended sediment carrying force are 0.185 and 0.666; the flocculation of the fine sediment is closely related to the particle size. The threshold particle size is 0.025mm; the initial roughness adopts the roughness during river flood period, which is 0.0422.

4. Influence of parameter adjustment on the model calculation results

In order to analyze the influence of each parameter on the model calculation results, this paper mainly adopts the single factor adjustment analysis method, that is, when sensitivity analysis is performed on a certain parameter, the other parameters are kept unchanged. Adjust the parameters by ±20% to compare the effect of this factor on the calculation model.

Table 1 shows the effect of each parameter adjustment on model calculation results. The table indicates that the larger the dry density, the smaller the cumulative sedimentation amount, and the sediment discharge ratio is almost unchanged; the change of the K of the water flow sedimentation parameter has almost no effect on the cumulative sedimentation amount and the sediment discharge ratio, however, the change of parameter m will cause variation in the cumulative sedimentation amount, and they are proportional; when the saturation recovery coefficient in siltation condition increases or decreases by 20% on the basis of 0.7, the corresponding cumulative sedimentation amount decreases; Considering the effect of flocculation of fine-grained on sediment when the threshold particle size increases or decreases by 20%, the calculation result of the cumulative sedimentation amount does not change.

5. Conclusion

Through the analysis above, following conclusion can be drawn:
(1) According to the sensitivity analysis of the parameters, the influence of dry density, water flow sedimentation parameters and recovery saturation coefficient have great affection on the calculation results, among which, the variation of dry density has the greatest influence.

(2) In the calculated river section, the size of the sand is rather small, where the sediment with a particle size of less than 0.01 mm accounts for 57% of the total sand. In this paper, the flocculation effect of fine-grained sediment is studied briefly. The results show that the effect of flocculation is not significant. Changing the value of the demarcation particle size has little effect on the calculation results.

(3) The natural sedimentation pattern of the reservoir is complex. In the calculation, considering the relevant influencing factors and the complexity of the model itself, the influencing parameters are simplified. In this paper, the effects of sediment carrying capacity change caused by sediment thickness variation and unbalanced sediment transportation is not thoroughly considered. Moreover, with the time passes, the change of reservoir topography will also cause the change in sediment carrying capacity and sediment concentration. They have increased the difficulty researching the sedimentation in reservoirs and will be the key in the future researching.

Table 1. Sensitivity analysis of various parameters.

| Influencing parameter                  | Before adjustment | After adjustment |
|----------------------------------------|-------------------|------------------|
|                                        | value             | cumulative sedimentation (/10^8 m³) | Sediment discharge ratio /% | Variation /% | value | cumulative sedimentation (/10^8 m³) | Sediment discharge ratio /% |
| Dry density / (kg/m³)                  | 800               | 1.15             | 71.7                      | +20          | 960   | 0.94             | 71.8                      |
|                                        |                   |                  |                           | -20          | 640   | 1.46             | 71.7                      |
|                                        | K=0.185           | 0.77             | 67.5                      | +20          | 0.222 | 0.77             | 67.5                      |
|                                        |                   |                  |                           | -20          | 0.148 | 0.77             | 67.5                      |
|                                        | m=0.666           | 0.77             | 67.5                      | +20          | 0.799 | 0.72             | 69.2                      |
|                                        |                   |                  |                           | -20          | 0.533 | 0.81             | 65.9                      |
|                                        | 0.7               | 0.82             | 66.3                      | +20          | 0.84  | 0.65             | 72.1                      |
|                                        |                   |                  |                           | -20          | 0.56  | 0.78             | 67.5                      |
|                                        | (threshold particle size/mm) | 0.025         | 0.86                      | 64.7         | +20          | 0.024 | 0.86             | 64.7                      |
|                                        |                   |                  |                           | -20          | 0.016 | 0.86             | 64.7                      |

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