Prediction of Riverbed Evolution under Different Operation Modes of Three Gorges Reservoir at A Reach with Beaches in Flood Seasons

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Abstract. Different reservoir operation modes in flood seasons will have a profound impact on the evolution of the downstream reach of the dam. In this paper, a sandy reach with beaches in the downstream of the dam is selected. Based on the water and sediment conditions output from the Three Gorges Reservoir under different operation modes in flood seasons, the erosion and deposition trend in the reach is predicted and calculated. The results show that the total inflow of the reach is basically the same during the operation period, but with the decrease of the controlled discharge, the action time of the bank full discharge increases, and the total scouring amount of the reach slightly increases, which is conducive to the development of the channel.

1. Introduction
Since the Three Gorges Reservoir entered the 175m experimental impoundment period in 2008 [1], aiming at the problems of flood control, water resources in dry season and shipping in the downstream of the dam, the Three Gorges reservoir has adopted peak shaving operation in flood season, impoundment in advance after flood season and water replenishment in dry season [2], which has changed the natural runoff process in the middle reaches of the Yangtze River. Among them, water supplement in dry season and water storage in advance after flood season mainly affect small and medium water flow, but have little influence on channel development. The peak shaving operation of reservoir in flood season is mainly aimed at the storage flood, which reduces the peak flow of Yichang station at the downstream of the dam, and the frequency of high water decreases, which reduces the flood control pressure of the middle and lower reaches of the Yangtze River. The maximum discharge of Yichang station since 2008 is 47600 m³/s. When the frequency of high water decreases, the probability of high shoal passing through the lower reaches of the dam decreases, which is directly related to the long-term development of the river. Taking 2012 as an example [3], there were four numbered flood peaks in the upper reaches of the Yangtze River during the flood season. The maximum inflow peak discharge of the Three Gorges reservoir was 71200 m³/s, which exceeded the flood in 2010. The Three Gorges reservoir carried out peak cutting and flood detention operation for the four floods, with the maximum discharge of m³/s (8:00 on July 31). The total flood storage of the four peak cutting operations was about 20.25 billion m³, which effectively reduced the flood control pressure in the middle and lower reaches of the Yangtze River.

During the middle and small flood regulation of the Three Gorges reservoir, due to the change of the flood action time of different discharge levels, the erosion and deposition of the downstream channel of the dam may be affected [4]. Based on the water and sediment conditions under different operation modes of the Three Gorges reservoir, this paper predicts the evolution trend of a typical Sandy River.
downstream of the dam. The research results can provide a reference for the optimal operation of the Three Gorges reservoir.

2. Study area and method

2.1. Study area
There are many beaches and deep troughs in the reach from Nianziwan to Yanchuantao, with very complex bed evolution. After the operation of the Three Gorges reservoir, the river section has undergone drastic adjustment, which has a very strong response to the operation of the Three Gorges reservoir. Therefore, this reach is very suitable for studying the evolution law under different dispatching modes. The study area of this paper is selected as this river section, with a length of about 90km as shown in Figure 1.

2.2. Method and data
A two-dimensional flow and sediment mathematical model is used to calculate the distribution of erosion and deposition [5-6].

2.2.1. Formulation of operation mode
In 2015, the Ministry of Water Resources approved the regulation for cascade operation of Three Gorges (initial operation period) - Gezhouba Water Control Project, which put forward the principal clause for medium and small flood operation. "When the flood control safety is fully guaranteed, the Three Gorges reservoir can carry out medium and small flood operation. The Yangtze River flood prevention and control general administration should constantly sum up experience, further demonstrate the conditions, objectives, principles, advantages and disadvantages of medium and small flood regulation, study and formulate the medium and small flood regulation scheme, and report it to the state flood prevention and control General Administration for approval."

In the regulation for cascade operation of the Three Gorges (initial operation period) - Gezhouba hydro junction (revised in 2019) approved by the Ministry of water resources in 2020, the medium and small flood regulation scheme to reduce the flood control pressure in the middle reaches of the Yangtze River is further refined. When the medium and small flood occurs in the upper reaches of the Yangtze River, the 5.65 billion m³ flood control storage capacity below 155m is used for medium and small flood regulation, and the applicable situation is put forward.

Therefore, this study focuses on the impact of different medium and small flood regulation methods on the short-term shaping of river channel. 2012, which has a large inflow, is selected as a typical flood year to formulate the operation mode of diversion magnitude of the Three Gorges Reservoir in flood season.

On the basis of the revised regulation in 2019, the study of medium and small flood regulation mode is carried out. The proposed main modes are as follows:
Mode 1: The maximum discharge is controlled to be 43000 m³/s;
Mode 2: Maximum discharge is controlled to be 45000 m³/s;
Mode 3: Maximum discharge is controlled to be 50000 m³/s;
Mode 4: Maximum discharge is controlled as 55000 m³/s.
2.2.2. Condition of inlet and outlet

The inlet discharge and outlet water level of the reach under each dispatching mode are provided by the one-dimensional mathematical model from Yichang to Datong [7], as shown in Figure 2. The inlet sediment concentration is determined by the relationship between discharge and sediment discharge of Jianli station in 2012 (see Figure 3), and the sediment concentration gradation is determined by the measured suspended sediment gradation in 2012.

Since the difference of water and sediment processes in different dispatching modes is only reflected in July to October, the calculation period in this section is from July 1 to October 31, 2012.
Figure 3 Relationship between discharge and sediment transport rate in 2012.

3. Results and discussion

3.1. Results

Table 1 shows the statistical values of scouring and silting amount under different dispatching modes. Figure 4 shows the distribution of erosion and deposition in mode 2, the recommended operation mode. It can be seen that with the increase of controlled discharge, the total scouring amount decreases slightly. When the controlled discharge is 43000 m$^3$/s, 45000 m$^3$/s, 50000 m$^3$/s and 55000 m$^3$/s, the total scouring amount of the whole channel is -7.80, -7.60, -7.02 and -6.81 million m$^3$ respectively, and the variation range of the maximum and minimum value is about 14.5%.

The scouring amount and the total scouring amount under the beach boundary are similar with the regulation mode, that is, the scouring amount decreases slightly with the increase of the controlled discharge. When the controlled discharge is 43000 m$^3$/s, 45000 m$^3$/s, 50000 m$^3$/s and 55000 m$^3$/s, the scouring amount of the channel under the beach boundary of the reach is -7.06, -6.78, -6.10 and -5.85 million m$^3$ respectively.

With the increase of controlled discharge, the inundation time increases. For the study reach, the channel above the beach boundary is scoured during the calculation period. With the increase of controlled discharge, the amount of scour increases slightly. When the controlled discharge is 43000 m$^3$/s, 45000 m$^3$/s, 50000 m$^3$/s and 55000 m$^3$/s, the amount of scour is – 0.75, -0.82, -0.92 and -0.96 million m$^3$ respectively.

Table 1  Statistics of scouring and silting amount under different dispatching modes (from July 1 to October 31).

| Channel                | Erosion and deposition (10$^4$m$^3$) |
|------------------------|--------------------------------------|
|                        | Mode 1  | Mode 2  | Mode 3  | Mode 4  |
| Under beach boundary   |   -705.7 |   -678.2 |   -609.5 |   -584.6 |
| Above beach boundary   |     -74.5 |     -81.6 |     -92.2 |     -96.4 |
| Total                  |   -780.2 |   -759.8 |   -701.7 |   -681.0 |
3.2. Discussion

From the above calculation results, it can be seen that for each calculation river reach, the total amount of discharged water in the calculation period is basically the same under different operation modes of the reservoir in 2012, and the difference only lies in the difference of peak discharge. The results show that the total scouring amount increases slightly with the decrease of controlled discharge, but the scouring and silting amount decreases slightly above the flat due to the decrease of flood time.

Under the current operation mode of the Three Gorges Reservoir with controlled discharge less than 45000 m$^3$/s, the flood channel downstream of the dam is mainly scoured and has a long-term development trend. At the same time, the scheduling experience has shown that the current dispatching method can effectively reduce the artificial and economic cost of flood control in the lower reaches of the dam, and also meet the requirements of initial design for reservoir desilting. Therefore, the current dispatching mode is a kind of dispatching mode which is favourable for the development of flood channel.

4. Conclusions

Based on the two-dimensional flow and sediment mathematical model, this paper calculates and analyses the scouring and silting laws of the typical reach downstream of the dam under different operation modes. The results show that the river bed is in the state of scouring development under different operation modes. The current operation mode of the Three Gorges reservoir, that is, to control the maximum discharge of 45000 m$^3$/s, is a kind of operation mode that can give consideration to the flood control benefits of the upstream and downstream of the Three Gorges reservoir, but will not cause the shrinkage of the flood channel in the downstream of the dam.

Acknowledgement

This work was supported by the research found of China Three Gorges Corporation (0704167).
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