Response of the Riverbed Evolution to Flood Process at A Curved Reach Downstream of Three Gorges Reservoir

Hua Ge1, *, Chunyan Deng1
1 Changjiang River Scientific Research Institute, Wuhan, Hubei, 430010, China
* Corresponding author: gehua@mail.crsri.cn

Abstract. The flood process has a very important impact on the evolution of the river. Based on the two-dimensional mathematical model of water and sediment, the response of the evolution of a curved reach downstream of the Three Gorges reservoir to different flood processes was calculated and analysed in this paper. The results show that under the premise of the same total amount of flood, when the flood process transits from the thin type to the short and fat type, the erosion amount of the channel increases gradually, but the increase extent of the channel above the beach reduced, resulting in the weakened erosion amount of the high beaches in the river.

1. Introduction
According to the development of the downstream channel of the built reservoir, some studies have shown that [1] since the 1960s, with the construction of a large number of water conservancy projects and the intensification of human activities, the inflow and sediment conditions in the lower reaches of the reservoir have changed significantly, such as the reduction of runoff, the flatten of flow process, the change of water volume ratio in flood season and dry seasons, the reduction of flood frequency, and the significant reduction of the ability of water flow to shape the riverbed.

After the impoundment and operation of the Three Gorges reservoir, the inflow and sediment conditions of the downstream channel of the dam have been also changed, such as the flood process, the duration of medium and small water, and the flood process, which may have a certain impact on the flood channel development of the downstream channel. As a result, this paper has analysed the influence of the evolution of a curved reach downstream of the Three Gorges Reservoir on different flood processes. The research results can provide a reference for the operation of the Three Gorges reservoir.

2. Study area and method
2.1. Study area
Tiaoguan reach is a curved reach located in the downstream of the Three Gorges reservoir. There are beaches and deep channels in the reach, and it is close to the Three Gorges Reservoir, so it has a sensitive response to reservoir operation. Therefore, this section is selected as the study area, as shown in Figure 1.

2.2. Method
In order to better simulate the channel evolution of beach and deep channels, the two-dimensional plane flow and sediment mathematical model is a better choice. In this paper, the vertical averaged two-dimensional flow and sediment control equations [2] based on orthogonal curvilinear grid [3] is selected. The equation is discretized by finite volume method [4] and solved by Simple algorithm [5].
2.3. Selection of flood process

According to the relevant laws and regulations, the overall flood control standard of the middle and lower reaches of the Yangtze River is to prevent the largest flood since the founding of the people's Republic of China, that is, the flood in 1954. Therefore, this paper selects the 1954 flood to generalize different flood processes, and the generalization method adopts the normal distribution curve model [6] to generalize the flood process. In general, the probability density function of normal distribution is as follows:

$$f(x) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$ (1)

Where $\mu$ is the non-position parameter, which is usually the mathematical expectation of a series, and $\sigma$ is the standard deviation, which is usually used to adjust the width and thinness of probability density, as shown in Figure 2.

![Map of the study reach.](image)

The generalization results of different flood processes are shown in Table 1. From the generalization results, the average discharge of different flood processes is 22291 m$^3$/s, and the bed forming discharge
of the study reach is 22000 m$^3$/s. With the increase of flood peak reduction, the number of days greater than the flat discharge increases gradually.

Table 1. Setting Word’s margins.

| Items               | 1954 | $\sigma=0.5$ | $\sigma=0.6$ | $\sigma=0.8$ |
|---------------------|------|--------------|--------------|--------------|
| Average discharge   |      | 22291        |              |              |
| bed forming discharge |    | 22000        |              |              |
| Flood days          | 44   | 50           | 54           | 56           |
| Variance            | 6.04 | 11.14        | 5.88         | 2.04         |

In the generalized flood process, different standard deviations correspond to different flood processes, but different processes correspond to the same total amount of flood. After the impoundment of the Three Gorges Reservoir, the sediment concentration along the downstream of the dam decreases sharply. Therefore, the sediment concentration process corresponding to the flood process cannot be generalized according to the sediment concentration process corresponding to the actual flood process in 1954. This generalization is based on the discharge sediment transport relationship of each station from 2013 to 2019 after the experimental impoundment of the Three Gorges reservoir. After the impoundment of the Three Gorges reservoir, the sediment concentration gradation of each station along the downstream of the dam has also changed greatly compared with that before impoundment. The average gradation during the flood period from July to September in 2013-2019 after the experimental impoundment of the Three Gorges reservoir is adopted in this calculation.

3. Results and discussion

3.1. Results

Table 2 shows the statistical results of channel erosion and deposition in different flood processes. Figure 3 shows the distribution of erosion and deposition during the 1954 flood. It can be seen from the table that when the standard deviation $\sigma$ of flood process is 0.5, 0.6 and 0.8 respectively, the flood process transits from thin and sharp type to short and fat type, and the scouring amount of basic channel increases.
gradually under the corresponding flood process, which are 2.01 million m$^3$, 2.36 million m$^3$ and 2.72 million m$^3$ respectively, while the scouring amount of flood channel is 2.73 million m$^3$, 3.00 million m$^3$ and 3.27 million m$^3$ respectively, which also shows a gradually increasing trend, but the increasing extent decreases. Therefore, the erosion amount of the channel above the flat, that is, the high beach channel in the channel, decreases successively, which are 0.72 million m$^3$, 0.64 million m$^3$ and 0.55 million m$^3$ respectively.

3.2. Discussion

From the calculation results, it can be seen that the short and fat flood process has stronger shaping effect on the flat channel and flood channel in the downstream of the Three Gorges Reservoir, while the sharp and thin flood process has stronger shaping effect on the channel above the flat channel, that is, the high channel in the channel. The reason shows that for general rivers, the bed forming discharge or flat discharge plays the most important role in shaping the riverbed shape.

Table 2. Statistics of scouring and silting amount in different generalized flood processes.

| Channel       | Erosion and deposition (10$^4$m$^3$) |
|---------------|--------------------------------------|
|               | Sharp      | short and fat |
|               | σ=0.5   | σ=0.6     | σ=0.8 |
| Main channel  | -201      | -236      | -272  |
| Flood channel | -273      | -300      | -327  |
| Above beach line | -72     | -64       | -55   |

For short and fat floods, the flat degree of discharge process is higher, and the duration of discharge process near flat discharge is longer, so it has stronger shaping effect on the whole channel. However, the large discharge in the process of the sharp and thin flood can act more on the high beach part of the channel, so the sharp and thin flood plays a stronger role in shaping the high beach channel above the flat. The variation law of the calculated values of channel erosion and deposition under different typical generalized flood processes can provide a certain reference for the operation of the Three Gorges reservoir, that is, if the flood volume after the flood peak can be reduced in the operation process of the Three Gorges reservoir, and the discharge after the flood peak can be released in the flood period or close to the flat flow, the overall scouring development of the flood channel downstream of the dam can be enhanced. The erosion of the high beach bed in the channel may be weakened.
Figure 3a. Distribution map of erosion and deposition when $\sigma=0.5$

Figure 3b. Distribution map of erosion and deposition when $\sigma=0.6$
4. Conclusions
In this paper, the normal distribution curve is used to generalize the flood process of curved reach in 1954 under the condition of ensuring the same total amount of flood, and the plane two-dimensional flow and sediment mathematical model is used to calculate and analyse the channel erosion and deposition under different generalized flood processes. The results show that under the premise of the same total amount of flood, when the flood process changes from thin to short, the scour amount of flat channel and flood channel increases gradually under the corresponding flood process, but the increase of flood channel decreases, resulting in the decrease of scour amount of channel above flat, that is, the high channel in the channel. Therefore, in the operation process of the Three Gorges reservoir, if the flood volume reduced after the flood peak can be released in the flood period after the flood peak, or in the near flat discharge after the flood peak, the overall channel in the downstream of the dam will not shrink, and even the scouring development of the overall channel in the downstream of the dam will be slightly enhanced, but the scouring of the high beach and riverbed in the channel will be weakened.

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

References
[1] C. H. Hu, J. G. Chen, Q. C. Guo. Regulation of Flow and Sediment Processes and Reform of Medium-Size Channel in the Lower Yellow River. Journal Of Tianjin University, 41, 9 (2008)
[2] Y. J. Yi, Z. Y. Wang, S. H. Zhang. Two-dimensional sedimentation model of channel bend. Part 1. Development of the model. Journal Of Hydroelectric Engineering, 29, 1 (2010)
[3] R. G. Wen, W. L. Wei, Y. L. Liu, P. Zhang. Technique of orthogonal curvilinear grid generation for regions with complicated boundaries. Engineering Journal of Wuhan University, 43, 4 (2010)
[4] W. L. Tian, W. Z. Rong. Flow Pattern Analysis Before and After River Regulation Works. Jilin Water Resources, 5 (2017)
[5] H. Fan, F. T. Zong, S. Guo. Numerical simulation of water environment - The research and progress of SIMPLE Algorithm. Environmental Science & Technology, 29, z1 (2006)
[6] M. Zhang, M. W. Zhang, G. Y. He, F. X. Zhang. Analysis of Erosion Efficiency in Different Flood Wave Type on Non-Floodplain Flood in Lower Yellow River, 38, 1 (2016)