Study on the Relationship between Siltation Amount and Pre-dam Water Level of Three Gorges Reservoir under New Water and Sand Conditions

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Abstract. In order to study the comprehensive influence of incoming water and sand level and pre-dam water level on sediment siltation in the Three Gorges Reservoir under the condition of new water and sand, this paper studies the coupling relationship between sediment sediment and pre-dam water level in the Three Gorges Reservoir under the condition of new water and sand based on the measured data of the Three Gorges Reservoir from 2003 to 2017. The results show that the relationship between siltation and pre-dam water level is different at different time scales, and from the perspective of long-term time period (annual or flood period), the amount of siltation is positively correlated with the water level before the dam. Besides, during a short period of time (monthly) the siltation is negatively correlated with it, which does not conform to the law of "the water level in front of rises with an increasing siltation", and the water level before the dam has little impact on it.

Keywords: Three Gorges Reservoir; siltation; the water level in front of the dam; coupling relationship; Influencing factors.

1 Introduction

Under the situation of water storage and sediment retention and new water and sediment in the upstream cascade reservoir group, the operation of the Three Gorges Reservoir is much better than that of the initial design. Many experts and scholars have conducted a series of studies on the impact of water and sediment on sediment accumulation [1][2]. Ren et al. [3] demonstrated the measures to comprehensively and systematically solve the sedimentation problem in the Three Gorges area The sediment of the Three Gorges Reservoir affects flood control, navigation, power generation and the ecological environment. Liu et al. [4] conducted a comprehensive analysis of the sedimentary characteristics of TGR from 2003 to 2018. Huang et al. [5] studied the latest progress and prospects of reservoir siltation and river scouring in the

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lower reaches of the Three Gorges Reservoir on the Yangtze River in China. Rasheed et al. [6] explored the variations of streamflow and sediment yield in the Mosul-Makhool Basin, North Iraq under climate change. Based on the measured data from 2003 to 2017, this paper conducts multi-factor coupling analysis of the sedimentation of the Three Gorges Reservoir from different aspects.

2 Materials and Methods

Based on the daily average sediment content and flow data of the main control stations in and out of the Three Gorges Reservoir in 2003~2017, the daily sedimentation, monthly sedimentation and annual sedimentation of the Three Gorges Reservoir in 2003~2017 were calculated by the sediment transport method. The relationship between sedimentation and different influencing factors in the Three Gorges Reservoir area was discussed from the perspectives of annual, monthly, flood season and non-flood season. The sedimentation of the Three Gorges Reservoir was analysed from different time scales and different operation periods, and the relationship between the sedimentation volume and the water level in front of the dam (WLFD) under the condition of new water and sediment was explored.

3 Results & Discussion

Since the Three Gorges Reservoir was put into operation, the water storage period has been divided into three stages according to the scheduling method, namely, the cofferdam storage period, the initial water storage period and the 175m experimental water storage period. The average operating water level before the dam is used to represent the overall operation of the reservoir, that is

$$\overline{Z_d} = \sum Z_d / N \tag{1}$$

In Equation 1, the average daily water level of the Three Gorges Reservoir (m); N is the number of days in the statistical period, from which the average operating water level of the reservoir is obtained by monthly, flood season, non-flood season and the whole year.

3.1 The relationship between the water level in front of the dam and sediment sedimentation at different time scales

Figure 1 shows the changes in the sedimentation volume and average water level in front of the dam since the Three Gorges Reservoir was impounded and put into use. As can be seen from the figure, since the operation of the Three Gorges Reservoir, the water level in front of the dam has gradually risen, and the mean WLFD during the flood season is lower than the annual average WLFD due to the use of the dispatching mode of "storage, clearing and draining mud". With a growing WLFD, the flow ve-

locity within the reservoir region decreases, sediment-carrying capacity of the water flow decreases, and the sediment carrying capacity of the reservoir weakens, so that the sediment accumulation increases. It can be seen from Figure 1 that in 2003~2012, the overall sedimentation volume increased with the elevation of the water level in front of the dam (except for the reduction of the annual sedimentation volume of individual dry water and less sediment), but in 2013~2017, due to the operation of the upstream Xiluodu, Xiangjiaba and other reservoirs, the sediment storage effect of the Three Gorges greatly reduced the amount of sediment entering the Three Gorges, resulting in a significant decrease in the sediment volume during this time period compared with before, which no longer conforms to the law of "the WLFD increases and the sediment volume raises".

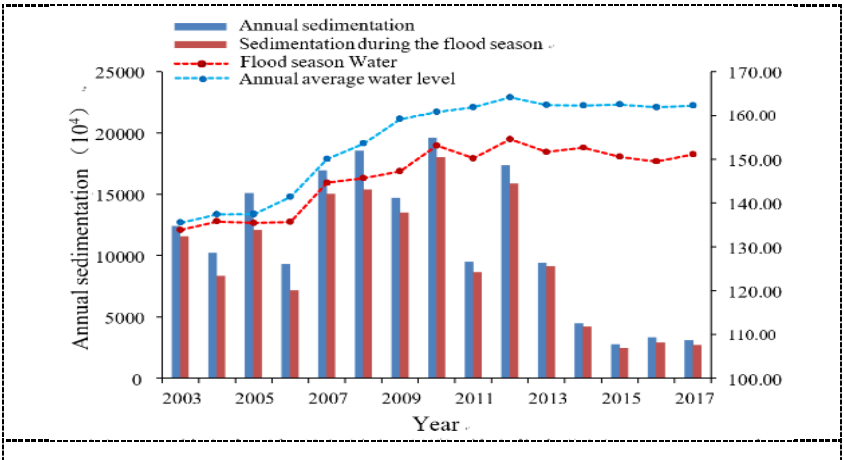

Fig. 1. Changes in siltation and average pre-dam level of Three Gorges Reservoir.

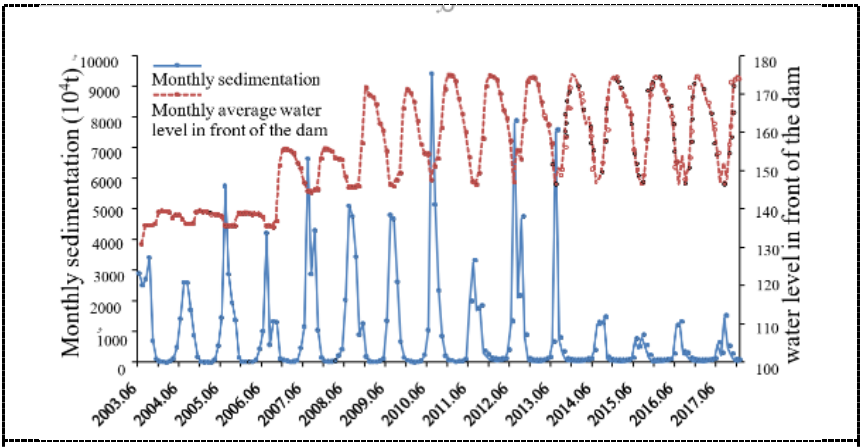

Fig. 2. Monthly sedimentation volume and monthly average dam water level change.

Figure 2 shows the monthly siltation volume of the Three Gorges Reservoir and the monthly average water level in front of the dam. As can be seen from the figure, the trend of monthly sedimentation is basically opposite to the trend of the WLFD, when the WLFD rises, the sedimentation decreases to the minimum value of each year, and when the water level in front of the dam decreases, the sedimentation volume increases to the maximum value of each year. This is related to the Saudi nature of the water coming from the Three Gorges Reservoir and the way it is dispatched. The run off and sediment transport of the Three Gorges Reservoir have the characteristics of seasonal variation, and the incoming water and sediment are mainly concentrated in the flood season, which accounts for more than 90% of the whole year, so the annual sedimentation is mainly concentrated in the flood season, reaching the maximum value in the flood season, and reaching the minimum value when the incoming water and sediment are the least in the non-flood season. However, the Three Gorges Reservoir adopts the dispatching scheme of "storage, clearing and draining muddy", which reduces the water level in front of the dam and discharges sediment when the flood peak is concentrated within the flood season, and raises the WLFD when the amount of water and sediment is small during non-flood season. That is, when the sedimentation volume increases rapidly with a large amount of water and sediment entering the reservoir during the flood season, the reservoir lowers the water level and discharges sediment, thereby reducing sediment sedimentation, maintaining the effective storage capacity of the reservoir, and achieving the purpose of long-term use of the reservoir.

To better analyse the correlation between the sedimentation volume of the Three Gorges Reservoir and the WLFD, the relationship between the sedimentation volume of the Three Gorges Reservoir and the average WLFD during the annual and flood seasons of the Three Gorges Reservoir is counted as follows figure 3 and figure 4.

It can be seen from the figure that since the operation of the Three Gorges Reservoir, the correlation between the annual sedimentation volume and the annual average WLFD is poor, and the correlation between the sediment volume and the WLFD during the flood season is slightly better, the correlation coefficient R2 between the two in 2003~2012 is about 0.4, and in 2013~2017, the sedimentation volume is greatly reduced due to the decrease of upstream sediment, and the correlation points become more scattered.

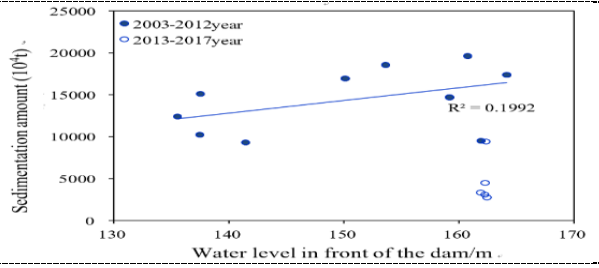

Fig. 3. Relationship between the annual siltation volume and the annual average water level in front of the dam.

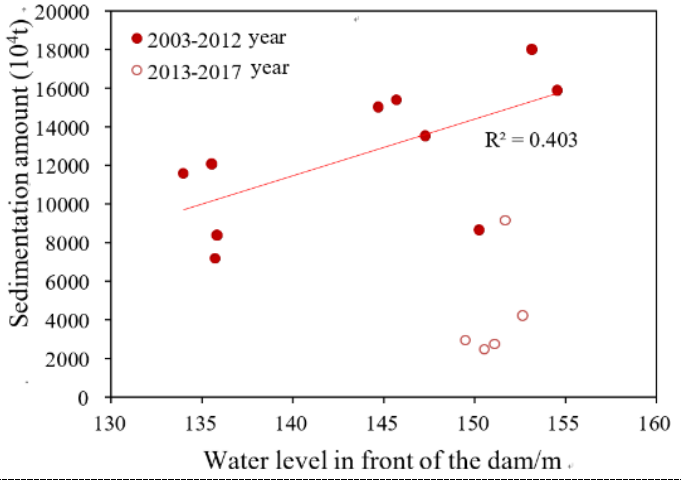

Fig. 4. Relationship between sedimentation and the average water level in front of the dam during the flood season.

3.2 The relationship between the water level in front of the dam and sediment sedimentation at different time scales

Figure 5 shows the correlation between the monthly siltation volume and the monthly average dam water level in different operating periods of the Three Gorges Reservoir. It seems that with the increase of the water level in front of the dam, the amount of sediment decreases, but in fact, the decrease in the amount of sediment at this time is also caused by the increase of the water level into the non-flood season, rather than the direct impact of the WLFD.

From the perspective of different periods of the Three Gorges Reservoir, the correlation coefficients between the sedimentation volume and the WLFD during the cofferdam impoundment period and the initial impoundment period were 0.52 and 0.72, respectively, and the point groups on the relationship diagram were slightly perpendicular to the abscissa, and the same water level in front of the dam corresponded to multiple sedimentation volumes and the change range was large, indicating that the water level in front of the dam was not the main factor affecting the sedimentation at this time, and the inflow and sediment content also had a great impact on the sedimentation. In October 2008 ~ September 2012, the Three Gorges Reservoir in the 175m experimental water storage period, the water level in front of the dam has risen, but the correlation between the sedimentation volume and the water level in front of the dam is relatively scattered, and the sedimentation volume changes greatly under the same water level in front of the dam, which is mainly due to the large change in the overall water and sediment in 2008~2012, of which 2010 and 2012 are abundant water and sandy years, and the flood season is concentrated in a large flood process, and the sedimentation volume can reach up to 94.38 million tons. 2011 was a typical

dry and sandless year, and the amount of sedimentation during the flood season was small. From October 2012 ~ December 2017, due to the storage and sedimentation of the upstream cascade reservoirs, the siltation of the Three Gorges Reservoir was greatly reduced, and the siltation volume was basically below 20 million tons, and the water level in front of the dam did not have much impact on it.

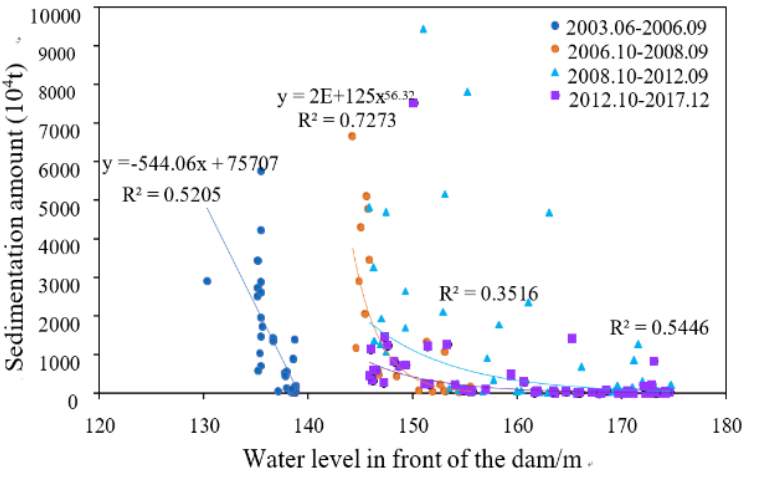

Fig. 5. Relationship between monthly siltation and monthly average water level in front of dam in Three Gorges Reservoir at different times.

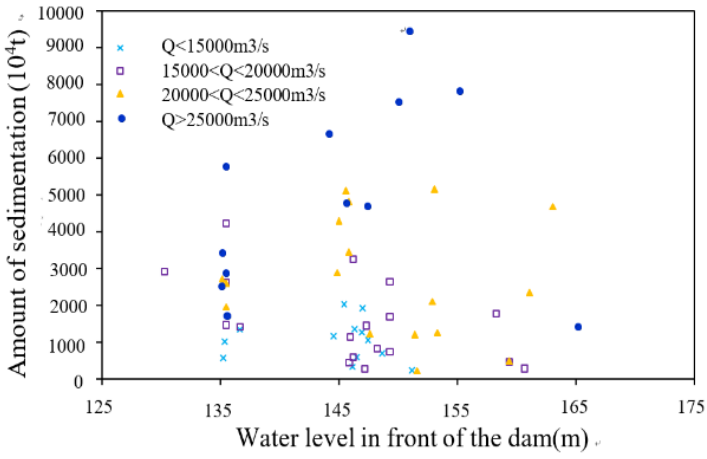

Fig. 6. Relationship between sedimentation volume and dam water level in front of the dam in different flow levels of the Three Gorges Reservoir.

It can be seen from the figure 6 that the relationship between the sedimentation volume and the WLFD during the flood season is scattered, and under the same

WLFD, with the increase of the average flow of sediment, the sedimentation volume shows an increasing trend, and some related relationship points are also greatly affected by the amount of sediment entering the reservoir, which is not in line with this growth trend. WLFD is not the key factor affecting the sedimentation volume, and the WLFD not only affects the sedimentation volume within the reservoir region, but also affects the inflow rate and sediment inflow. Therefore, a comprehensive analysis is needed for the influence of various factors on sedimentation.

4 Conclusion

In general, the water level in front of the dam has a certain impact on the amount of siltation. Due to the dispatching characteristics of the Three Gorges Reservoir, the relationship between the water level in front of the dam and the sedimentation volume no longer simply follows the general law of "the water level in front of the dam rises (decreases) and the sedimentation volume increases (decreases)". When the water level is high, the Three Gorges Reservoir is mostly in the storage period, and the water level in front of the dam has little impact upon the sedimentation volume, and the sedimentation volume is at a small level. In addition, the effect of the WLFD upon the sedimentation volume is best analysed in combination with the water and sediment conditions of the Three Gorges Reservoir, and the correlation of a single analysis is not very good. The conclusions drawn can provide reference for the operation of the Three Gorges Reservoir.

Acknowledgments

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