Main influencing factors of sediment peak transmission time in flood season of the Three Gorges Reservoir (TGR)

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Abstract: Based on the measured data of sediment peak transport after the application of the TGR, the relationship between sediment peak transmission time and different influencing factors in the TGR was studied. The result shows: Main influencing factors of sediment peak transmission time in flood season of the TGR are sediment peak concentration of Cuntan station and flood retention coefficient, and the relationship between them is the positive proportion, in which the influence of inflow sediment peak on the sediment peak transmission time is greater than flood retention coefficient. Research results can provide reference for Sediment regulation of the TGR during flood season.

1. Introduction

River flood peaks are transmitted in the form of waves, while the transport of sand peak is related to the flow velocity of the water, and the propagation speeds of the two are different. Due to the small water depth of the natural river channel, the sediment movement and the phase of the water flow movement have no great difference. The sand peak process is generally similar to the flood peak process. After the reservoir was built on the river, due to the deepening of the water depth, the flood peak propagation speed in the reservoir area was accelerated, and the sand peak propagation speed was obviously slowed down. The phase difference of the water-sand process greatly increases, and the closer to the dam, the more the peaks of the sand-peak propagation process lag.

According to the statistics of the measured data, after impoundment of the TGR, the time the warehousing peak reached the dam was shortened from about 54 hours before the water storage to about 6~12 hours. And the time the sand peak reached the dam was extended from about 2-3 days before the water storage to about 3-8 days. The phase alienation of water and sediment causes the sand peaks in the reservoir to lag behind the flood peaks, and the hydrodynamic conditions of the sediments discharged from the reservoir are weakened, the sand peaks are attenuated along the way, and the sediment discharge capacity of the reservoir is reduced. In the flood season dispatching process of the TGR in 2012 and 2013, in order to take into account the sediment discharge of the dam, a preliminary attempt of sand discharge scheduling has been carried out in the real-time dispatching. Increasing the discharge flow of the reservoir when the sand peaks reach the dam, improving the amount of sediment discharged from the reservoir, can obtain a better effect of sediment discharge and siltation. Dong Bingjiang summed up the sand peak dispatching strategy and dispatching mode of the TGR [1, 2] for
the flood peak cutting when the flood peak arrives and the flood discharge when the sand peak approaches. Zhang Diji et al. pointed out that “the attenuation of sand peaks in the reservoir area is mainly related to the length, flow and sediment particles of the river section” [3]. Dong Nianhu et al. analyzed the data of sediment transport of the TGR in the flood season in 2007. It is believed that at a large flow rate the propagation time of the sand peak in the reservoir area is about 6 days, which is 2 to 3 days longer than in the normal time, and increase more at a small flow rate [4]; After analyzing the measured data of the TGR in 2003, Zhou Jianjun believed that the sandstone propagation time in the TGR was 3–4 days longer than the flood peak, and the reasons for the delayed peak of the sand peak propagation were analyzed [5]. Generally speaking, the research on the propagation time of the sand peak period in the flood season of the TGR is still relatively small, mostly limited to the rough statistics of the propagation time of the sand peak, and the lack of in-depth study on the factors affecting the transmission time of the sand peak, makes the sand peak dispatching practice lack of science. This also increases the uncertainty of sand peak dispatching, which is not conducive to the maximum effect of siltation scheduling.

In this paper, based on the measured data of sand peak transport after the impoundment of the TGR, the main influencing factors of the sand peak propagation time of the TGR are studied. The study determines the controlling dominant factors affecting the propagation time of the TGR during the flood season, and the research results can provide reference for the sediment regulation of the TGR in flood season.

2. The selection of the measured data of sediment peak

In order to study the propagation time and attenuation of sand peak from the entrance of Cuntan Station to the Huanglingmiao Station, we first selected the more obvious sand peak process in the measured average water and sediment process at Cuntan Hydrology Station. The sand peak that can be selected for research must appear in the Qingxichang, Wanxian, and Huanglingmiao stations in turn. The same sand peak should appear in the downstream station no earlier than the upstream station, and it should be able to present a relatively complete reservoir transfer process, the daily average water and sediment process is used for each hydrological station data, and the flood sedimentation process data can be used as a reference. Finally, from the measured water and sediment data in the reservoir area since the TGR was used, 28 sets of sand peak transport data were selected. The time range of the selected sand peak data is from June 2003 to December 2013. The measured time of the sand peak propagation from Cuntan to Huanglingmiao ranges from 2 to 8 days. The variation range of sand peaks at the Cuntan Station is 0.842–5.45kg/m³, and the variation range of the sand peaks at the Huanglingmiao Station is 0.007–1.4kg/m³. When the sand peaks are stored, the flow range of the Cuntan is 13100–63200m³/s and the flow range of Huanglingmiao varies from 12900 to 43800 m³/s. When the sand peaks are stored, the water level in front of the dam varies from 135.1 to 162m. After the sand peaks, the water level change in front of the dam is -1.18~11.37m. The sand peak sediment concentration, sand peak propagation time, inflow flow rate, and water level in front of the dam are widely distributed in this set of sand peak transport data, which can reflect different sand peak conditions, with strong representativeness and the research results have a large scope of application. Figure 1 shows mainstream and its tributaries and the hydrological station location of the TGR.
3. The study on the main influencing factors of sand peak propagation time

A statistical analysis was performed on the relationship between the different influencing factors such as the measured time $T$, and flow of sand peaks $Q$, the sediment concentration of sand peaks $S$, and the storage capacity of the flood storage capacity $V$ (the total storage capacity at a certain water level before the dam can be obtained by linear interpolation of the water storage capacity curve). $T_{TGR-huang}$ stands for the sand peak propagation time from the TGR’s Cuntan Station to the Huanglingmiao Station. $Q_{cun}$ stands for the measured average daily flow of Cuntan on the Cuntan station on the day of the sand peak. $Q_{huang-sediment}$ stands for the measured average daily flow of Huanglingmiao on the Huanglingmiao station on the day of the sand peak. $Q_{cun-flood}$ stands for the peak flow of Cuntan Station during the flood peak process corresponding to the sand peak process. $Q_{huang-flood}$ stands for peak flow of Huanglingmiao Station during the flood peak process corresponding to the sand peak process. $V_{start}$ stands for the flood storage capacity corresponding to the water level in front of the dam when the sand peak is put into storage. $V_{end}$ stands for the flood storage capacity corresponding to the water level in front of the dam when the sand peak is out of the reservoir. $V_{average}$ stands for the flood storage capacity corresponding to the average water level in front of the dam in the process of sand peaks entering and leaving the reservoir. $V_{max}$ stands for the flood storage capacity corresponding to the maximum water level in front of the dam in the process of sand peaks entering and leaving the reservoir. Define the flood retention coefficient $V/Q$ ($V$ for the flood storage capacity, $Q$ for the reservoir flow) (the same below).

3.1. Relationship between sand peak propagation time and flow rate

From the statistical analysis of the relationship between the sandstone propagation time $T_{TGR-huang}$ of the TGR and the characteristic flow of the inbound and outbound reservoirs $Q_{cun}$、$Q_{huang}$、$Q_{huang-sediment}$、$Q_{huang-flood}$、$Q_{cun-flood}$, it is found that the correlations are relatively poor, and the distribution of related points is relatively scattered. The linear regression determination coefficients $R^2$ are all within 0.05 (Fig. 2). It can be seen that the sand peak propagation time of the TGR is greatly affected by other factors than the inflow and outflow.

Figure 1. Mainstream and its tributaries and the hydrological station location of the TGR
3.2. Relationship between sand peak propagation time and sediment concentration

The correlation between the time of sand peak propagation $T_{\text{cun-huang}}$ and the sediment concentration of the five peak hydrological stations in the reservoir, such as the Cuntan, Qingxichang, Wanxian, Miaoh and Huanglingmiao, was statistically analyzed. It is found that the correlation between $T_{\text{cun-huang}}$ and the sediment concentration $S_{\text{cun}}$ of Cuntan Station is relatively best, and the two are proportional to each other, and the linear regression determination coefficient $R^2$ of the two reaches 0.5952 (Fig. 3).

It can be seen that the sediment concentration $S_{\text{cun}}$ in the sand peak of Cuntan Station is an important factor affecting the propagation time of the sand peak of the TGR.
3.3. Relationship between sand peak propagation time and flood storage capacity

Statistical analysis was carried out on the correlation between the transmission time \( T_{cun-huang} \) of the sand peak and the storage capacity of the flood storage \( V_{\text{start}}, V_{\text{end}}, V_{\text{average}}, V_{\text{max}} \). It is found that the two are basically proportional, the correlation is relatively poor, the distribution of related points is scattered, and the linear regression coefficient \( R^2 \) is between 0.09 and 0.11 (Fig. 4). The linear regression coefficients are all small and they are very close.
3.4. Relationship between sand peak propagation time and combination factors

Based on the previous research, some of the main influencing factors were combined. The two combined variables initially selected were: flood retention coefficient \( \frac{V}{Q} \) and sand concentration \( S \). The flood retention coefficient \( \frac{V}{Q} \) characterizes the length of time that the inflow flood stays in the reservoir. The study found that the propagation time of the sand peak is proportional to the flood retention coefficient \( \frac{V}{Q} \), but the correlation between the two is relatively scattered. When \( \frac{V}{Q} \) equals to \( V_{\text{start}} / \left( \frac{0.5(Q_{\text{cunl}} + Q_{\text{huangl}})}{10^4 s} \right) \), the linear regression determination coefficient \( R^2 \) reaches a maximum of 0.206. Combine the sediment concentration of the sand peak \( S_{\text{cun}} \) with the flood retention coefficient \( V_{\text{start}} / \left( \frac{0.5(Q_{\text{cunl}} + Q_{\text{huangl}})}{10^4 s} \right) \) as an independent variable for statistical analysis. Compare the situation when the storage capacity \( V = V_{\text{end}}, V_{\text{average}} \), it is found that the correlation between the sand peak propagation time \( T_{\text{cun-huang}} \) and the combined variables \( S \cdot V/Q \) is good, and the two have a significant positive correlation. The regression decision coefficients \( R^2 \) differed very little, between 0.6717 and 0.6793 (Figure 5).

3.5. Analysis of results

From the statistical analysis results, the main influencing factors of the sand peak propagation time \( T_{\text{cun-huang}} \) in the flood season of the TGR are the sediment concentration \( S_{\text{cun}} \) and flood retention co-

![Graphs showing the relationship between sand peak propagation time and combination factors](image-url)
efficient $V_{\text{start}}/\left(0.5(Q_{\text{cun}} + Q_{\text{huang}})\right)$ of the sand peak at the Cuntan Station. The unit of flood detention coefficient $V/Q$ is $10^8$ s, which reflects the length of flood transfer time in the reservoir area. Therefore, it can be considered that the sand peak propagation time $T$ can be regarded as a function of the sediment concentration $S$ of the storage sand peak and the water flow transfer time $t$ of the reservoir area, and is proportional to the sediment concentration of the storage sand peak and the transport time of the water flow. Previous studies have shown that the linear regression determination coefficients $R^2$ of $T_{\text{cun-huang}}$ with $S_{\text{cun}}$ and $V_{\text{start}}/\left(0.5(Q_{\text{cun}} + Q_{\text{huang}})\right)$ is 0.5952 and 0.206, so $S_{\text{cun}}$ has a higher degree of influence to $T_{\text{cun-huang}}$ than $V_{\text{start}}/\left(0.5(Q_{\text{cun}} + Q_{\text{huang}})\right)$.

From Fig. 5(d), the correlation between the peak propagation time $T_{\text{cun-huang}}$ and the combination factor $S_{\text{cun}}V_{\text{start}}/\left(0.5(Q_{\text{cun}} + Q_{\text{huang}})\right)$ is the best, but the correlation point group has a band width distribution of a certain width, which also reflects the influence of other factors. The above research reveals the main influencing factors of the sand peak propagation time of the TGR, and also lays a foundation for the next study of the sand peak propagation time formula.

4. Discussion

Based on the data of 28 sets of measured sand peaks from June 2003 to December 2013 in the TGR, the paper analyzes the relationship between the peak propagation time and different influencing factors of the TGR during flood season. The main conclusions are as follows:

(1) The main influencing factors of the sand peak propagation time $T_{\text{cun-huang}}$ of the TGR are the sediment concentration $S$ and flood retention coefficient $V/Q$ of the storage sand peak. The sediment concentration $S$ of the sand storage peak in the reservoir is recommended to use the sediment concentration $S_{\text{cun}}$ of the Cundan station. The flood retention coefficient $V/Q$ is recommended in the form of $V_{\text{start}}/\left(0.5(Q_{\text{cun}} + Q_{\text{huang}})\right)$. $S_{\text{cun}}$ has a higher degree of influence to $T_{\text{cun-huang}}$ than $V_{\text{start}}/\left(0.5(Q_{\text{cun}} + Q_{\text{huang}})\right)$.

(2) The peak propagation time $T$ can be regarded as a function of the sediment concentration $S$ of the storage peak and the water transport time $t$ in the reservoir area, and is proportional to the sediment concentration of the storage sand peak and the transport time of the water flow. This study laid the foundation for the study of the time series of sand peak propagation.

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