Monitoring and analysis of external deformation of face rock-fill dam during initial storage period

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Abstract: During the initial storage period of the face rock-fill dam, its physical and mechanical properties will not be in a fully controlled state when it is subjected to the test of water loads, which may cause certain safety risks. The stability of the dam body and slope can be analyzed by studying the external deformation changes of the face rock-fill dam after water storage. This article analyzes the external deformation monitoring data of the Hekou Village Reservoir's face rock-fill dam during the initial storage period, and it reveals the general rule of the external deformation of the face rock-fill dam after water storage. The results also show that the dam is safe after storing water and have certain reference significance for other similar projects.

1. Introduction
The concrete face rock-fill dam has a rock-fill body as a supporting structure, and a concrete face plate as an anti-seepage structure is provided on the upstream surface. This kind of dam has the characteristics of low geological requirements for the dam foundation, strong stability of the dam body, and high cost performance. It is gradually becoming a dramatically competitive type[1~2]. The initial storage period is the first time that the hydraulic structure is subjected to water load. All aspects of performance are tested for the first time, and it is in a state of non-full control. Therefore, during this period, the hydraulic structure is in a high incidence of accidents. In order to understand the impact of water load in the initial storage period on hydraulic structures, it is necessary to arrange reasonable safety monitoring facilities[3].

The face rock-fill dam of Hekou Village Reservoir experienced high water level, rapid rise and fall of water level in the three years after impoundment. Moreover, the dam is equipped with comprehensive monitoring facilities, and during this period, rich observation data was obtained. This article focuses on the analysis of the external deformation changes of the left and right bank slopes of the face rock-fill dam during the initial storage period. It also studies the general rules of external deformation before and after water storage, and it explores the reasons for the changes. The research results can provide references for similar projects.

2. Project Overview
The Hekou Village Reservoir is located at the exit of the last canyon of the Qin River, a primary tributary of the Yellow River. It plays a pivotal role in controlling the flood and runoff of the Qin River, and it is an important part of the flood control engineering system in the lower Yellow River. The dam site of Hekou Village controls catchment area of 9223 km². Furthermore, the scale of Hekou Village Reservoir...
Project is large (2) type, and the project grade is II. It consists of concrete faced rock-fill dam, 1 # spillway, 2 # spillway, diversion power tunnel, and hydropower station. The maximum height of the dam is 22.5 m, and the length and width of the crest is 530 m and 9 m respectively.

The dam started construction on the high-pressure rotary jet grouting pile in the main pile area in May 2011, and the dam began to fill in March 2012, until the main body of the dam was filled to 286 m in December 2013. In addition, the Hekou Village Reservoir started to store water for the first time in August 2014, and the highest water level for the first storage was 249.68 m (2015.6.22). On June 23, 2016, the reservoir discharged for the first time. Moreover, the second storage began on August 7, 2016. The highest water level of the second storage was 262.70 m (2016.11.26), and the second discharge was conducted on June 30, 2017.

3. External deformation arrangement
According to the requirements of the national earth-rock dam safety monitoring technical specifications and the specific conditions of the Hekou Village Reservoir Project, 4 monitoring sections are arranged on the downstream side of the dam body to monitor the surface deformation of the dam body, and 19 observation points are arranged. Moreover, there are 6 observation points on the left bank slope, 7 observation points on the right bank slope, and 4 observation points on the spillway.

4. Analysis of monitoring results
4.1. Dam
4.1.1. Deformation analysis of left and right banks
It can be seen from monitoring the change trend of each measuring point of section 0 + 140 that measuring points deformed to the right bank as a whole, and the deformation trend to the right bank slightly increases after water storage. However, the change trend after the second discharge is not obvious. Currently, the 0 + 140 section behind the dam deformed to the direction of the right bank.

Figure 1 The surface deformation process line of the left and right banks of section 0 + 140 behind the dam

4.1.2. Analysis of deformation in the upstream and downstream directions
The crest of the dam and the observation points of the slopes behind the dam generally deformed to the downstream, showing a certain correlation with the change in water level. It can be seen from monitoring the change trend of each observation point of section 0 + 140 that the initial water storage level is low, and each measurement point shows a deformation trend to the downstream. After impounding in August 2016, the highest water level was 262.70 m, and the deformation of each observation point to the downstream increased. Due to the continuous adjustment of the seepage field and gravity, the settlement also causes horizontal displacement. After the water level is gradually stabilized, the surface deformation of the dam crest and the slope behind the dam gradually stabilizes. After the second discharge, the downstream deformation tendency of several observation points has slowed down.
Vertical deformation analysis

The vertical deformation of the observation point of the crest of the dam and the slope behind the dam has a positive correlation with the change of the reservoir water level. When the water level rises, the settlement rate increases. After the reservoir is filled with water, the dam body under the action of water mainly produces three effects, including water pressure, buoyancy and humidification deformation. Both the water pressure and the seepage force acting on the upstream surface of the dam can be decomposed into horizontal and vertical component forces, and the vertical component forces cause the vertical displacement of the dam body. In addition, due to the lubricating effect of water and under the action of water pressure and buoyancy, the soil particles are readjusted under the effect of self-weight, so that the soil compresses and sinks, resulting in humidification and deformation. Since the seepage field and stress redistribution of the dam body are in the process of continuous adjustment after water storage, based on the above three factors, the settlement of each measuring point in the initial storage period still has a certain increase trend. After the water level is gradually stabilized, the surface deformation of the dam crest and the slope behind the dam gradually stabilizes. After the second discharge, there was a slight change in the settlement of the 0 + 140 section behind the dam.

Figure 3 Vertical deformation process line of section 0 + 140 behind the dam

According to the results of the surface deformation monitoring points arranged on the dam crest, the current height of the dam crest is 288.222m to 288.264m.

4.2. The slope of left bank

Figure 4 Surface deformation process line of the left bank slope in the vertical directions
During the water storage period, multiple observation points on the left bank slope were flooded and could not be observed. After the second discharge, the observation points were exposed. It can be seen from the figure that all the measuring points on the left bank slope deformed to the direction of the river, which is stable at present. Affected by the second discharge, some observation points deformed slightly in the vertical direction. In addition, the horizontal and vertical deformations have a certain lag compared to the reservoir water level changes.

4.3. The slope of the right bank

We obtain the reference value from observation points on the right bank slope after initial water storage. Due to the low initial water storage level, the deformation of the right bank slope is less affected by water storage. It can be seen from the figure that under the influence of the second water storage, each measuring point deforms to the river. And after the second discharge, it still showed an increasing trend of deformation towards the river. The change of each measuring point in the upstream and downstream directions is slight, and it is currently showing a stable trend. The point D5-24 is free from both sides of the measuring point, and the position stability is weak, while the settlement and deformation of the other measuring points changed slightly. In addition, due to the fact that there is a large amount of accumulation in the right bank, the current deformation trend is not obvious, but people need to pay more attention to these points continuously.

4.4. Spillway

Figure 6 Surface deformation process line of the spillway in the left and right bank directions

Figure 7 Surface deformation process line of the spillway in the upstream and downstream directions
The observation points of the spillway slope are located on both sides of the downstream spillway of the dam. After the initial water storage, the horizontal deformation is not obvious, and the settlement deformation increases slightly. It can be seen from the figure that the deformation trend of the observation point of the spillway slope to the left bank has increased due to the second water storage, and it has gradually stabilized. In addition, after the second water storage, the observation points displaced in the downstream direction, and the change is more obvious, while after the second water discharge, the deformation in each direction is not obvious.

5. Conclusion

After the dam is impounded, in the direction of the left and right banks, the monitoring point has a slightly increasing deformation trend to the right bank; the monitoring points deformed to the downstream in the upstream and downstream directions and have a certain correlation with the change of the reservoir water level. In the vertical direction, as the water level rises, the settlement rate increases, which is positively correlated with the reservoir water level change.

The observation points on the left bank slope deformed to the direction of the river. In the upstream and downstream directions, they deformed to the upstream direction, while the deformation in the horizontal and vertical directions has a certain lag compared with the change of the reservoir water level.

The observation points on the right bank slope deformed to the direction of the river, and the changes in the upstream and downstream directions are not obvious. There is the settlement of a single measuring point that is significantly affected by the terrain.

The deformation trend of the observation points on the spillway slope to the left bank has increased, and the observation points all displaced in the downstream direction. The settlement deformation of the observation points has also increased, while the amount of change is not obvious.

Through the analysis of the external deformation monitoring results of the Hekou Village's face rock-fill dam, it can be seen that after the reservoir is filled with water, the deformation of the dam and the left and right bank slopes changes as the water load increases, and it follows the general law. The dam and the left and right bank slopes are stable before and after impoundment.

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