Seepage analysis of Baihetan arch dam

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Abstract. The 289m high arch dam at Baihetan has good indicators before water storage, but after water storage, seepage gradually occurs in the dam body and foundation parts, which has some adverse effects on the safety of the dam. In this paper, five monitoring instruments were used to analyze the overall dam properties during the water storage process, including the pre-buried foundation corridor pressure tube, the dam base seepage pressure gauge, the seepage pressure tube around the dam, the dam water measuring weir and the dam base drainage hole. The results show that: the seepage pressure level before the curtain of the dam base is seriously affected by the upstream water level, Post-curtain and post-drainage lift pressure is less affected by upstream water level; the flow rate of the dam measuring weir and the dam base drainage hole is more affected by the upstream water level, and the trend of flow rate changes is more consistent with the trend of the upstream water level; the rest of the parts are less affected by the upstream water level.

1. Introduction
China began to build hydropower stations on a large scale in the 1950s, and the initial construction of hydropower stations was small in scale and low in difficulty, and the construction process was relatively simple. With the introduction of some advanced technology from abroad, China gradually began to increase the scale of hydropower plant construction, and the construction of the Rong Hong Dian arch dam in 1956 used the cooling water pipe technology from abroad; at the same time, the Liu Xi River arch dam also used this technology. By the time the Baishan arch dam was built in the 1970s, China's dam construction technology had been greatly improved, and the infrastructure capacity had been increased accordingly. After the construction of these projects, the scale of China's hydropower plants gradually increased, and by the time the Ertan arch dam was built in the 1990s, it had developed into a super project. At this time, the original technology is difficult to meet the needs of these super projects, in the construction process of these super projects, in order to clearly understand the working state of the project, it is necessary to bury certain monitoring instruments in the dam body and nearby locations, to analyze the overall state of the project. During the construction of the Xiaowan Arch Dam, some intelligent monitoring equipment was gradually added, and by the time the Xiluodu Arch Dam was built, it had been developed into an intelligent construction. Many manual steps were performed by machines, which improved efficiency and reduced human errors. When the Xiluodu arch dam was built, the arrangement of monitoring instruments was very comprehensive and the monitoring system was gradually formed [1-4]. For the seepage part, it is mainly monitored by five kinds of instruments:
foundation corridor pressure measuring tube buried at the base and body of the dam, seepage pressure meter at the base of the dam, seepage pressure measuring tube around the dam, dam water measuring weir and dam drainage hole [5-6].

Baihetan Hydropower Station is located on the main stream of Jinsha River at the junction of Ningnan County, Sichuan Province and Qiaojia County, Yunnan Province, China. The main function is to generate electricity, but also to prevent floods, stop sand and improve navigation. The dam type of the hydropower plant is a hyperbolic arch dam with a crest elevation of 834.00m, a minimum base elevation of 455m and a maximum dam height of 289m.

In the monitoring system of Baihetan, the foundation corridor manometer, dam base seepage manometer [7], and seepage flow manometer around the dam are mainly used for the monitoring of the lift pressure of the dam body and the dam base, but also to test the effect of the impermeable curtain. The dam measurement weir and dam base drainage holes are mainly used for dam and dam base drainage flow monitoring. The foundation corridor manometer measures the lift pressure before the curtain, behind the curtain and behind the drainage; the dam base seepage manometer monitors the infiltration pressure at the shoulder slot of the arch dam; the seepage flow around the dam manometer monitors the upstream reservoir water around the shoulder of the dam to the downstream; the dam gauging weir and the dam base drainage hole monitor the total seepage flow of each dam section and the dam base.

2. Monitoring data analysis

2.1. Project Profile
Baihetan Hydropower Station started initial water storage since November 2020 with a target water level of 640 m. After the initial storage, the inflow bottom hole of the dam began to overflow. After the upstream water level reached 640m, the water level was maintained at about 640, which lasted until April 1, 2021, when the diversion bottom hole was lowered and the second water storage started, and the upstream water level continued to rise, with the water level rising about 5m a day at the beginning, and the subsequent rate decreasing, and finally the upstream water level was maintained at 760m.

2.2. Foundation corridor pressure measurement tube
There are 28 pressure measuring pipes behind the foundation gallery curtain and 27 pressure measuring pipes behind the foundation gallery drainage. When the dam was initially impounded, the lift pressure level behind the foundation gallery curtain and behind the foundation gallery drainage changed relatively little and remained basically stable until April 1, 2020. When the dam was stored for the second time, there was a significant rise in the lift pressure level after curtain and drainage. In this paper, we analyze the changes in the lift pressure level behind the curtain and drainage after the second impoundment of the dam. The maximum head of the post-curtain pressure tube after the second impoundment of the dam is at the foundation grouting gallery of the 18-dam section, and the head of the measurement point is 60.77 m. The water level changes between -1.20 m and 46.05 m after the second impoundment, respectively, in the 30-dam section and the 8-dam section. The maximum head of the pressure pipe after drainage is at the foundation drainage corridor in dam section 6, with a measured head of 35.07 m. The water level changes between -0.87 m and 8.27 m after storage. In Figure 1 below, it can be clearly seen that the post-curtain and post-drainage lift pressure water levels are distributed from the riverbed dam section to the steep-slope dam section with a gradual increase from low to high. The typical sections 17 and 18 of the riverbed dam are selected to analyze the trend of the post-curtain and post-drainage lifting pressure levels, as shown in Figure 2. As a result, it can be concluded that the dam curtain before and after the curtain lifting pressure water level is in a normal state.
2.3. Dam base seepage pressure meter
Nine seepage gauges were buried at the base of the arch dam and nine at the shoulder of the dam. The seepage gauges at the base of the dam were used to monitor the actual head seepage before the curtain at the later stage, and the seepage gauges at the shoulder of the dam were used to monitor the seepage at the structural surface after the treatment of the fault at the shoulder of the dam. The water level in the first storage was low, and only the water level in front of the dam base curtain had a certain degree of increase in the lifting pressure, while the dam shoulder slot remained almost stable. After the second water storage, the water level in front of the curtain rose rapidly, and the water level at the shoulder of the dam increased to a certain extent, but the change was small. In Figure 3, it can be seen that there is a small increase in the water level in front of the curtain during the first impoundment, and after the
second impoundment, the water level in front of the curtain rises rapidly and follows the upstream water level. In Figure 4, it can be seen that the upstream water level changes have little effect on the water level in the shoulder slots of the dam, which basically remains stable. The seepage pressure gauge data at the dam base and shoulder slots are basically in the normal range.

![Figure 3. Riverbed dam section pre-curtain seepage pressure gauge timing process line.](image1)

**Figure 3. Riverbed dam section pre-curtain seepage pressure gauge timing process line.**

2.4. Seepage pressure measurement tube around the dam

The seepage around the dam can monitor the upstream reservoir water bypassing the shoulder of the dam to the downstream 65 pressure measurement tubes have been installed. During the first impoundment, the upstream water level rise has a small impact on the around seepage level, and during the second impoundment, the around seepage level has a certain degree of lift, with the maximum head reaching 56.57 m. The amount of around seepage level change after the second impoundment ranges from -5.70 m to 22.45 m. Figure 5 below shows the typical seepage time sequence process line around the dam. It can be seen in the figure that the water level around the seepage basically remains stable.

![Figure 4. Variation of seepage pressure gauge at dam base with upstream water level.](image2)

**Figure 4. Variation of seepage pressure gauge at dam base with upstream water level.**
after the first impoundment, and there is a slow increase in the water level around the seepage after the second impoundment, and the water level around the seepage also stabilizes as the upstream water level tends to stabilize.

![Figure 5. Right Bank Dam Base OH-WMR1-1 Water Level Timing Process Line.](image)

2.5. Dam measurement weir

The dam measuring weir mainly monitors the flow rate of the drainage holes of the foundation corridor. 93 measuring weirs have been installed in the dam corridor, and the current flow rate ranges from 0.0 L/min to 585.69 L/min, with a total seepage volume of 1178.82 L/min. As can be seen in Figure 5, the total flow rate of the measuring weir in the foundation corridor changes less and remains basically flat during the first water storage, and during the second storage, the total flow change of the measuring weir is consistent with the trend of upstream water level change. Figure 6 shows the process of the maximum flow volume weir, and it can be seen that the trend is basically in line with the upstream water level. At present, the flow rate of the dam's water measuring weir is basically stable, and no abnormal situation occurs.

![Figure 6. Process line diagram of the total flow of the foundation corridor measuring weir.](image)
2.6. Dam base drainage holes

The dam base drainage holes mainly monitor the base drainage corridor and the drainage holes at the dam site drainage corridor, and the current general measurement covers dam section 15#-21#. As shown in Figure 7, the total flow rate of the dam base drainage holes started to increase after the first water storage, but the total flow rate of the drainage holes did not increase steadily, and after the second water storage, the total flow rate of the drainage holes basically increased steadily with the upstream water level, and now it tends to be stable. The data of the drainage holes at the base of the dam are stable with the stabilization of the upstream water level, and there is no abnormal problem.

3. Conclusions

By analyzing the monitoring data of the foundation corridor pressure gauge, dam base seepage gauge, seepage flow gauge around the dam, dam water measuring weir and dam base drainage holes, Baihetan Hydropower Station is influenced by the upstream water level during water storage, but the seepage flow of the dam is in the normal range with no abnormalities and the overall condition of the dam is good.
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