Analysis of anomalies measured by the osmometer in a roller compacted concrete arch dam

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Abstract: The water permeability of the RCC dam layer and joint surface is high, which often becomes the main channel of dam body seepage, and its safety monitoring is important. Based on the monitoring data of the osmometer of a roller compacted concrete (RCC) arch dam, this paper analyzes the abnormal seepage pressure of the dam body, and introduces the relevant inspection and treatment scheme, which can provide a reference for the construction and operation of other RCC dams.

1. Introduction
Roller compacted concrete (RCC) dams have the characteristics of low cement consumption, low hydration heat, monolithically rolling, fast construction speed and low overall cost [1], which have been widely used in China. A number of high RCC dams such as Longtan, Huangdeng and Guangzhao dams [2] have been constructed. In order to ensure the safe operation of these high dams, prototype observation is an indispensable and important method, which is an important basis for studying and judging the dam safety.

The permeability of the RCC dam body differs greatly from that of normal concrete, but the water permeability between layers and on the joint surface is large, which often becomes the main seepage channel of the dam body [3]. Based on the observation data of the osmometer installed on the long intermittent surface of a RCC arch dam, this paper analyzes the abnormal seepage pressure, and introduces the relevant inspection and treatment scheme to provide a reference for other similar dam construction.

2. Monitoring layout
The RCC arch dam under study here has a dam foundation elevation of 504.5 m, a dam crest elevation of 646 m, and a maximum dam height of 141.5 m. In order to monitor the anti-seepage performance and construction quality of the concrete, five main monitoring sections of the dam body were selected, and three osmometers were arranged on the roller compaction construction level of the upstream corridor at an elevation of 514 m, 565 m, and 610 m to monitor the seepage pressure of the roller compaction layer, and the seepage pressure distribution at different positions in the impervious layer of the dam was measured.

At present, the osmometers that showed abnormal changes are located at the upstream side of the dam at elevation 514 m, where three osmometers have been deployed, as shown in Figure 1. Among
them, P4-5 measuring point is 1-m away from the upstream surface, P4-6 measuring point is 3.5-m away from the upstream surface, and P4-7 measuring point is 8.5-m away from the upstream surface.

![Figure 1. Layout of osmometer at an elevation of 514 m in the No.5 dam section](image)

3. Anomaly analysis

3.1. Brief introduction of anomalies

In the process of dam construction, the seepage pressure water head appears at P4-5 and P4-6 measuring points. The seepage pressure water head of the P4-6 measuring point is the largest, followed by P4-5 measuring point, and P4-7 measuring point shows zero pressure.

1. There are three obvious change stages of the pressure head at the P4-6 measuring point. The process line is shown in Figure 2, and the change process is as follows:

   - The first increment occurred between December 16, 2017 and February 4, 2018. At this time, the concrete at this measuring point was in the process of later cooling and water supply, and the temperature dropped from 24.7 ℃ to 14.6 ℃, and the osmometer increases from zero pressure to a water head of 1.69 m.
   - The second increment occurred between December 15, 2018 and January 10, 2019. At this time, the clay backfill was in progress in front of the dam, and the backfill elevation was EL.507.5-EL.535 m, the water level in front of the dam would when rainwater and construction water entered, which was confirmed by the increase of the measured value of the osmometer on the upstream side of the foundation of several main monitoring sections. At this time, the seepage water head at the P4-6 measuring point increased from 0.94 m to 3.86 m.
   - The third increment started from June 22, 2019, this increment was caused by the heavy rainfall in this period. The water level of the upstream cofferdam in the evening of June 21 has exceeded 550 m, and the range of ponding in front of the dam also changed greatly. On July 14, 2019, the seepage water head at the P4-6 measuring point increased from 0.94 m to 3.86 m.

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![Figure 2. Water head pressure changes at the P4-6 measuring point](image)
was basically between 6 m and 8 m before borehole inspection.

(2) There are two obvious change stages of pressure head at the P4-5 measuring point. The process line is shown in Figure 3, and the change process is as follows:

![Figure 3. Changes in the water head pressure at the P4-5 measuring point](image)

① The first increase occurred between December 16, 2017 and December 30, 2019. The seepage pressure head of the P4-5 measuring point began to increase gradually after the clay backfill in front of the dam (December 16, 2017), but the growth rate was still relatively slow at this time. From December 15, 2018 to June 22, 2019, the seepage pressure head increased from a non-pressure state to a water head of 2.19 m; After that, with the increase of rainfall and the change of water level in front of the dam, the seepage head increased rapidly, and by December 30, 2019, the seepage head was 5.63 m. The change law of the measuring point reflects that the leakage channel here is gradually expanded under the action of the water head in front of the dam.

② The second increase occurred between December 30, 2019 and March 12, 2020, which was the initial impoundment stage of the reservoir. The water level in front of the dam rose to an elevation of 550.8 m, the seepage water head increased, and the maximum seepage head was 8.67 m, which occurred on March 9, 2020.

3.2 Investigation of causes for anomalies

(1) Problems with the instrument

The imported string type osmometer was selected for the seepage pressure monitoring of the dam body of this project. It was inspected and tested in accordance with the requirements of the specification before installation [4], and the instrument cables were also tested, and all indexes met the design requirements, and the installation was also carried out in strict accordance with the specification and design requirements during the construction process. After the osmotic water head appeared in the osmometer, referring to DL / T 1271-2013 "Specification for Appraisal of Vibrating Wire Sensor" [5], and the osmometer was tested on site. The test results of frequency range, temperature range and insulation resistance all met the specification requirements, and it could be determined that the instrument was normal was in a normal working state, and the anomalies caused by the problem with the instrument itself and the cable failure could be basically ruled out.

(2) Borehole inspection

① In order to thoroughly investigate the cause of abnormal change of osmometer, three inspection holes are arranged on both sides of the 515 foundation corridor osmometer (with a distance of 2 m) for investigation. The layout of inspection holes is shown in Figure 4. The results show that the permeability of other holes is 0Lu except Y1 and Y2 which were connected to each other (about 1-1.7 L / min).
The measured values of osmometer before and after drilling were observed. Before the inspection hole was constructed, the seepage pressure head of P4-6 measuring point was 5.77 m, and after the inspection hole construction, the seepage pressure head was reduced to 1.65 m. There was no change in the measured values of seepage pressure head of P4-5 measuring point before and after the construction of inspection hole. Through the field inspection, the water head of the osmometer was basically consistent with the water level of the inspection hole, and there was a small amount of water out of the Y1 and Y2 holes. Based on this, it is preliminarily determined that the internal water head pressure of the concrete was released after drilling, and there was a correlation between the drop of water head and inspection holes Y1 and Y2 and osmometer P4-6.

After checks of the water pressure in holes Y1 and Y2, the inspection scheme of water pressure inspection and osmometer observation synchronization was adopted to judge the correlation between inspection hole and osmometer. According to the results of water pressure test and monitoring, the water head of the osmometer also increased with the increase of water pressure during the water pressure inspection, and the data of the osmometer changed obviously. From the monitoring data, the seepage pressure head of P4-6 measuring point and the pressure value of the water pressure test were relatively consistent, indicating that there was indeed a problem of communication and mutual connection between the Y1 and Y2 inspection holes and the P4-6 osmometer. Table 1 and Table 2 show the inspection results of water pressure and the monitoring results of osmometer measuring points P4-6 and P4-5.

| Hole No. | Hole depth(m) | Hole diameter(mm) | Water pressure (MPa) | Segment length (m) | Permeation rate (Lu) |
|----------|---------------|-------------------|---------------------|-------------------|---------------------|
| Y1       | 8.52          | 76                | 0.4                 | 7.25              | 0.46                |

| Measuring point No. | Location       | Observation time | Water head | Remarks                  |
|---------------------|----------------|------------------|------------|--------------------------|
| P4-6                | From upstream face 3.5m | 2019-10-15 09:26:00 | 1.99       | Before water pressure test |
### 3.3 Comprehensive analysis

1. From the perspective of spatial distribution, the seepage pressure of P4-5 and P4-6 measuring points changed, and P4-7 was in a non-pressure state, indicating that the expansion depth of the leakage channel has reached to 3.5 m (P4-6 measuring point) from the upstream surface, but has not reached 8.5 m (P4-7 measuring point). In terms of time distribution, the seepage pressure of P4-6 measuring point changed first, which indicates that the leakage channel did not develop horizontally from P4-5 measuring point on the upstream side; otherwise, the P4-5 measuring point which is closer to the upstream side would change first.

2. It can be concluded from the data of water pressure results that the water permeability of Y1 and Y2 concrete water pressure test holes was 0.46Lu, which met the anti-seepage requirement of 1Lu; the Y2 hole was 10 cm from the top of the osmometer, and the Y1 hole was 70 cm from the bottom of the osmometer, both of which passed through the 514-m elevation surface, the flow rate of the two holes was small during the pressurized water period, and the flow of Y1 and Y2 holes was only 1.0L/min–1.7L/min; During the pressurized water inspection, there was no water absorption and collusion problems in other adjacent holes, and there was no obvious defect in the concrete around the osmometer.

3. The elevation of No.4-5 dam section on the left bank of the dam was within the range from 510.20 m to 514.00 m, the interval time between layers of the RCC in this pouring range was long (116 days), which was a long interval layer. At the same time, the layer has experienced a low temperature season. It can be seen from [6] that the permeability characteristics of RCC layers are affected by many factors, among which the most basic is the interval time of layers. The longer the interval time is, the greater the water permeability is. The long interval time of layers at an elevation of 514 m is unfavorable to the anti-seepage performance of the dam body, which should be the main cause of abnormal osmometer.

According to the above monitoring data and analysis of water pressure results, combined with thematic discussion and expert advice, there may be small-range local micro and short cracks developing horizontally or obliquely around the 514 m elevation osmometer of 5 # dam section.

### 3.4 Treatment measures

According to the changes of upstream water level and monitoring data after the first stage of impoundment, the Y1 and Y2 inspection holes which were related to the abnormal situation of osmometer were treated by epoxy chemical grouting at the end of April 2020, and the grouting pressure was 0.3 MPa. Figure 5 shows the process lines before and after the seepage pressure head grouting at P4-5 and P4-6 measuring points.
As the figure shows, under the influence of grouting pressure, the seepage pressure head of P4-5 and P4-6 measuring points increased from 8.59 m and 5.93 m to 23.73 m and 25.36 m, respectively, and then gradually decreased and tended to be stable. By the end of the second stage of water storage, the seepage pressure heads were 12.59 m and 13.27 m respectively. It should be noted that the seepage water head after grouting treatment does not represent the true water head value of the part, because it is affected by the grouting pressure. Whether the local micro cracks in this part are effectively blocked depends on whether the measured value of the osmometer increases further after the second stage of water storage. If the seepage pressure head increases further, relevant measures can be taken for secondary treatment.

4. Conclusion
(1) The RCC dam has its special and complex seepage characteristics, so the dam seepage monitoring is very important. In addition to the monitoring items required by the design, some monitoring instruments can be added according to the actual situation in the construction, such as deploying piezometers and joint meters on the long intermittent surface and wintering surface.

(2) The layer bonding of the RCC dams should be improved to avoid the long intermittent layer. If long intermittent layer cannot be avoided, relevant layer treatment methods should be adopted to increase the layer bonding quality to improve the impermeability of concrete [7].

(3) Safety monitoring is an important means to ensure the safe operation of dams. Full attention should be paid to monitoring results, and inspection and treatment measures should be taken in time after anomalies are found, and problems should be addressed in a timely manner.

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