Discussion on deformation monitoring method of asphalt concrete core wall of high earth-rock dam

Cui Hai-bo, Liu Bao-xin, Zhang Chen-liang, Wang Yong-hui, Ji Xiang
Power China Beijing Engineering Corporation Limited, Beijing, 100024, China
E-mail: cuihaibo109@163.com

Abstract: The deformation of asphalt concrete core wall of earth rock dam is an important monitoring item of safety management in the construction and operation period of the project. This paper summarizes the conventional monitoring methods and principles of the deformation of asphalt concrete core wall, analyzes the application scope and existing problems of the conventional monitoring methods, and introduces a new method and principle of the deformation monitoring of asphalt concrete core wall of high earth rock dam, which effectively solves the problems. The problems of conventional monitoring methods are solved, and the three-dimensional deformation monitoring of asphalt concrete core wall is realized.

1. Introduction
Asphalt concrete core wall is the core part of the earth-rock dam anti-seepage system, which acts as an anti-seepage barrier. The operating state of asphalt concrete core wall is an important basis for judging the success of the anti-seepage body. Therefore, the core wall deformation monitoring is the focus of the entire hub safety monitoring task. According to the technical standard, the core wall deformation is also an item that must be monitored. Through the monitoring of the deformation of the asphalt concrete core wall, as well as the analysis and feedback of the results, we can timely grasp the operating status of the hydraulic structure, verify the optimal design, monitor the construction quality, and ensure the safe operation of the building.

2. Conventional monitoring methods
The core wall deformation monitoring includes two stages: construction period monitoring and operation period monitoring. During the construction period, the asphalt concrete core wall is affected by its own weight, the soil-rock pressure on both sides and the vibration force of the construction machinery rolling, which mainly produces vertical and horizontal thickness changes; during the operation period, the asphalt concrete core wall mainly produce horizontal displacement, affected by the water pressure and humidification effect of upstream and downstream transition materials and rockfills [1]. Based on this, a certain monitoring method is usually adopted to monitor the deformation of the core wall horizontal displacement and vertical deformation in two dimensions. The conventional method is to use a combination of c and borehole inclinometer, that is, the settlement deformation of the core wall is monitored by electromagnetism type settlement gauge, and the horizontal displacement of the core wall is monitored by borehole inclinometer. According to their usage, inclinometers can be divided into movable inclinometers and fixed inclinometers. The former is generally used in the construction period and requires manual observation. The latter is generally used in the operation period and can realize monitoring automation.
2.1 Monitoring Principle

(1) Electromagnetism type settlement gauge[2]: Pass the anchor point with permanent magnet through the measuring tube axis and anchor it in bedrock or stable structure of underground, along with dam body filling, bury the settlement ring or settlement plate at each necessary elevation measurement point, then using measuring probe to measure the displacement between the measuring point and the anchor point, an last the settlement deformation can be calculated. Generally, the anchor point at the bottom of the bedrock is selected as the most optimal choice, because the calculation is more convenient and the accuracy is higher. More specifically, the absolute displacement of the other measurement points relative to the anchor point represents settlement deformation. Also the external vertical deformation reference point can be selected to calculate the core wall settlement by calculating the relative displacement among other measuring points, the top of the observation pipe and the anchor point.

(2) The borehole inclinometer: The inclinometer tube is buried and installed at the position where need to be measured downstream of the core wall to obtain the horizontal displacement in the whole hole depth range perpendicular to the drilling axis. The inclinometer tube cannot be bent and measuring line is approximately a straight line. For movable inclinometer measurement method, the data can be measured manually section by section from the bottom of the concave guide channel to the orifice step by step. For fixed inclinometer measurement, the data can be collected automatically by installing sensors embedded in each elevation measurement point in the inclinometer tube and processed by computer.

2.2 Existing problems

The method of measuring the deformation of the core wall by the combination of the electromagnetism type settlement gauge and borehole inclinometer is generally applicable to the middle and low dams with a dam height of 70m or less. The application of this method to high dams has the following problems:

(1) Poor representation. The location of the survey line is at a certain distance from the core wall, which approximately reflects the deflection and deformation of the core wall and is poorly represented. On the one hand, since the surface of the asphalt concrete core wall is generally not in a plane. Especially the asphalt concrete core wall earth-rock dam above 150m level, considering the complexity of the mechanical properties of asphalt concrete [3], the bottom of the core wall is connected to the bed of concrete through the enlarged feet with varying thickness to improve its mechanical properties and impermeability. So the surface can’t be in a plane. In addition, the integrated anti-seepage structure of "asphalt concrete core wall + concrete base" cannot be occupied and penetrated by the inclined tube in principle. On the other hand, the conventional embedding method of the inclinometer pipe needs to avoid the influence of the construction machinery of the wall. Therefore, it is difficult for the inclinometer to fit the asphalt concrete core wall. The measured data can not accurately represent the core wall deformation.

(2) Construction is difficult. Inside the inclinometer, there are four concave guide grooves with symmetrical distribution in cross shape, which are used as the upward and downward sliding tracks of the inclinometer pulley. The direction of the guide groove is strict, and a group of grooves should be aligned in the expected displacement direction. With the increase of the length of the buried measuring tube, the installation of the guide groove is prone to twisting and deformation, and the quality of the embedding is difficult to guarantee. The measurement error also increases.

(3) When the fixed inclinometer is installed in the pipe for automatic observation, the number of measurement points is limited by the pipe diameter, the error of the observation result is large, and the installation process is cumbersome. At present, the maximum diameter of the inclinometer is 72mm, and the diameter of the built-in instrument is 32mm (excluding pulleys and other components). The clearance can accommodate 16 cables, that is, the number of measuring points arranged longitudinally in the measuring line is less than 16. It is better to arrange the measuring points at an interval of 5m, but for a dam over 70m, with the increase of the dam height, the distance between the measuring points will increase, the data on the deflection curve will be discontinuous, and the curve fitting error will be large.
In addition, there are many mechanical connections to be assembled in the installation process. The whole set of inclinometer requires a large number of mechanical connectors, and the installation process is complicated. In the installation process, once the connectors fall into the hole, because it is difficult to salvage, the inclinometer hole will become a waste hole.

(4) The process of manual observation is tedious and heavy, and it can't realize three-dimensional automatic monitoring. During the construction period, when the movable inclinometer is used for manual observation, relatively more measuring points can be set to reduce the fitting error of deflection curve, but the workload is proportional to the number of measuring points. The observation process is tedious and inefficient. It takes a long time. Taking the 100m high asphalt concrete core wall as an example, the measurement standard distance is generally 0.5m, which is measured once for each distance measurement axis symmetrical direction, that is, one inclinometer needs to move the probe and observation record in the pipe manually for 400 times to complete the measurement, and the standard stipulates that the deformation monitoring of the core wall is monitored more than once a week during the construction period, so the manual observation intensity is high, the workload is large, and errors are easy to occur in the process, and it can't realize automatic monitoring.

3. A new method
This paper provides a new type of monitoring system and method for asphalt concrete core wall deformation of high earth-rock dams. The monitoring system includes monitoring datum, shape acceleration array (SAA), protective tube, and data acquisition device. Install the SAA on the downstream surface of the core wall according to the prescribed method [4], SAA and the core wall will deform synchronously. The bottom of SAA is fixed on the monitoring datum, and the outer side of the SAA which is flexible above the monitoring datum is sheathed with protective pipe. The top of the pipe and displacement gauge is connected to the data collection device set on the crest of the dam. Through the data collection device and supporting software, the three-dimensional deformation monitoring data of the asphalt concrete core wall is automatically obtained.

![Figure 1. Schematic diagram of deformation monitoring system for asphalt concrete core wall of high earth-rock dam](image)

In the picture, 1—asphalt concrete core wall; 2—concrete foundation; 3—SAA; 4—protective tube; 5—monitoring datum; 6—cable; 7—data collection device 8—Transition layer first area; 9—Transition layer second area; 10—Upstream rockfill; 11—Downstream rockfill.
3.1 Principle of above monitoring method
The above method mainly measures the three-dimensional deformation of each measuring point relative to the fixed end through SAA, so as to obtain the overall deformation of the core wall. SAA is a sensor based on microelectronic mechanical system test principle [5-6] to test acceleration and displacement. It consists of multiple segments connected in series. Each segment has a built-in three-axis accelerometer, which can measure the inclination in three orthogonal directions to determine the three-dimensional attitude of the measured object. By detecting the gravity field of each part, the bending angle $\theta$ between the shafts of each section can be calculated, the deformation $\Delta X$ of each section of SAA can be obtained through the bending angle $\theta$ and the known length $L$ of each section, that is, $\Delta X = L \cdot \sin \theta \approx L \cdot \theta$. And then sum the arithmetic $\sum \Delta X$ of each segment to obtain the deformation $X$ of any length from the fixed endpoint.

![Figure 2. Calculation diagram of SAA](image)

3.2 Advantages of above monitoring method
The method introduced in this paper not only effectively solves the problem of deformation monitoring of asphalt concrete core walls of high earth-rock dams, but also has the following advantages compared with conventional monitoring methods:

1. More accurately obtain the three-dimensional deformation of the core wall. The SAA has the characteristics of being bendable, flexible, and multi-dimensional deformation, so the measuring line can be fitted to or close to the core wall and deformed synchronously with the core wall, which fundamentally solves the problem of poor representativeness of conventional monitoring methods. The minimum distance between measuring points of SAA can reach 20cm, so monitoring data can be obtained continuously. It basically eliminates the fitting error between the points and further improves the representativeness and accuracy of the core wall deformation curve, and realizes three-dimensional deformation monitoring.

2. Easy installation and burial. When the monitoring system is installed and buried, the direction is easy to control, the outlet is simple, the quality of the embedding is easy to control, and it does not occupy or weaken the main body of the anti-seepage body.

3. The monitoring method has a high degree of automation, and almost no manual intervention is required during data collection and processing, which greatly reduces the workload of observation, improves the efficiency of observation, and avoids human errors.

4. Conclusion
This paper proposes a method of core wall deformation monitoring, which effectively solves the problem of deformation monitoring of asphalt concrete core walls of high earth-rock dams. The method has higher monitoring data accuracy, stability and reliability, simple installation and embedment, and quality control. The observation workload is small and the degree of automation is high. It can truly reflect the deformation of the core wall during construction and operation, and realize the three-dimensional deformation monitoring of the core wall.
Reference

[1] Ning C. (2018) Research on key technologies for health diagnosis of asphalt concrete core wall dam. D. Master degree thesis of Chongqing Jiaotong University.

[2] Zhang X.L., Yang Z.Y. (2013) Handbook of Hydraulic Structure Design: Volume 11 Hydraulic Safety Monitoring. M. 2nd Edition. Water Conservancy and Hydropower Press, Beijing.

[3] Liu S.J., Kong C.F., Yang J., etc. (2019) Design of 170m high asphalt concrete core rockfill dam in Quxue hydropower station. J. Hydropower and pumped storage, 5:31-35.

[4] Zhang C.L., Wang Y.H., Cui H.B., etc. (2019) A deformation monitoring system for earth-rock dam impervious core. P. Chinese patent: cn208872285u, May 17.

[5] Wei Y.C. (2015) Study on SAA measurement technology and its application in slope monitoring. D. Master's thesis of Nanjing University.

[6] Xu X., Ma Y.C., Zhai C.R., etc. (2007) Method and analysis of three-dimensional MEMS acceleration performance test. J. Microcomputer Information, 23 (2): 208-210.