Application of Data Analysis and Interpolation Method of Safety Monitoring System in a Water Conservancy Project

Shufeng Zhen1,2, Jianguo Wang2, Qi Wang3*

1 Shandong Yellow River Engineering Group Corporation Ltd., Jinan, Shandong, 250013, China
2 Xinjiang Ili River Basin Development & Construction Administrative Bureau, Urumqi, Xinjiang, 830000, China
3 China Renewable Energy Engineering Institute, Beijing, 100120, China

*Corresponding author’s e-mail: qfwq007@163.com (Q.W.)

Abstract. Dam safety monitoring data analysis and project operation management should keep pace with the development of monitoring technology. Taking the application of DSIMS4.0 system developed by Nan Jing Nan Rui Group Co. ltd. in Xinjiang water conservancy project as an example, this paper highly summarizes the scientific support of the system for dam operation performance analysis and effective management of dam.

1. Introduction
A water conservancy project is a large (I) type in Class I project, which consists of three major parts: a barrage, a flood discharge structure and a water diversion and power generation system. The main structures are classified as follows: clay core rockfill dam, surface hole flood discharge hole, middle hole flood discharge hole, deep hole sand discharge hole and water intake of water diversion and power generation system are Class 1 buildings; Water diversion and power generation tunnels and the powerhouses are Class 2 construction. The maximum dam height is 108 m, the length of dam crest is 362 m, the width of dam crest is 12.0 m, the upstream dam slope is 1: 2.5, the downstream comprehensive dam slope is 1: 2.33, and the crack prevention degree is 9 degrees. The powerhouse is a shore-based powerhouse on the ground and consists of an upstream auxiliary, a platform between the powerhouses and dams, a main power house, a tailrace platform, a tailrace canal, etc. The powerhouse has a total length of 127 m and is equipped with four 320 MW water turbine generators. The project is an earth-rock dam with a height of more than 100 meters on the upper reaches of cross-border rivers at home and abroad. The safe operation of the reservoir is directly related to the safety of people's lives and property in China and downstream countries. It is responsible for the operation, management, maintenance and repair of flood control, irrigation and power generation equipment and facilities of the multipurpose project.

2. Engineering Safety Monitoring System
According to the collection method of monitoring data, the safety monitoring system of the project can be roughly divided into two categories: manual collection and automatic collection.

Information management and analysis system can provide a good means of data management and analysis, which is the brain and soul of the whole security monitoring system. A good management
system can not only give full play to the role of monitoring system in monitoring engineering safety, but also greatly improve the efficiency and quality of engineering safety management.

In view of the characteristics of the project, such as complete monitoring items, multi-measuring points, and long monitoring period. A reasonable hierarchical structure is the key to ensure the reliable operation of the whole monitoring system. The measurement and control system is mainly composed of three layers: measurement layer, data acquisition layer and monitoring layer. The network structure is shown in Figure 1.

Features of system functions:
(1) The system organically combines communication technology, automatic control technology and computer application technology to form an automatic data acquisition, transmission and processing system, and provides the final processing results to management personnel in a timely and intuitive manner.
(2) The special software of the system solves the technical problems of remote service, online data collection, reporting, graph making, offline analysis, dam safety document management, measured value prediction, monitoring data compilation, database management, etc., and realizes high quality and efficiency of dam and engineering safety management.
(3) The system is stable and reliable, flexible to use, convenient to maintain and strong in expansion performance; Lightning protection, moisture resistance and anti-interference capability are strong.

Figure 1. Monitoring system structure.

3. System Application

3.1. Application of interpolation and extraction of monitoring data
If the measured data are relatively sparse for some reason, it is difficult to meet the calculation requirements in series analysis and prediction. At this time, reliable data of adjacent measurements or measuring points need to be used for interpolation. Interpolation can be divided by principle into physical mechanics interpolation and mathematical interpolation. Physical mechanics interpolation is mainly based on the known data, and the functional relationship between effect quantity and
dependent variable is analyzed, and then the interpolation is carried out by using the relationship. Mathematical interpolation methods mainly include linear interpolation method, Lagrangian interpolation, polynomial interpolation method, etc. For detailed principles, please refer to relevant mathematical monographs. When the data are too closely measured and affect the analysis efficiency, the data can be extracted according to the requirements. The main methods include extraction by time, extraction by measurement, etc.

Taking the seepage pressure of 0+175.00 section of the project as an example, interpolation calculation and analysis are carried out:

Section 0+175.00 is the largest section of the dam, and 9 seepage pressure meters are buried in the foundation (13 seepage pressure meters are arranged in the whole section). S01 is located 8 m upstream of the dam axis and 31.58 m deep into the foundation. S02 is located 2 m downstream of the dam axis behind the curtain and 11.38 m deep into the foundation. S03 and S04 are buried on the joint surface of clay and concrete (bottom plate) of the core wall, and the dam wheelbase is -15 m and 15 m respectively; S05 is located on the foundation surface of the transition material 31.5 m downstream of the dam axis; S06, S07, S08 and S09 seepage pressure gauges are all buried on the foundation surface of dam shell material downstream of the dam, with the dam axial distances of 47 m, 100 m, 130 m and 190 m respectively.

In the clay core wall, 935 m elevation (S10, S11) and 965 m elevation (S12, S13) are respectively embedded with two seepage pressure meters. The dam wheelbase of S10 and S11 are respectively 4 m above the shaft and 15 m below the shaft. The dam wheelbase of S12 and S13 is 2.89 m above the shaft and 8.12 m below the shaft respectively.

S01~S13 are Roctest PWS vibrating wire osmometer with measuring ranges of 0.35 MPa, 0.5 MPa, 0.7 MPa, 1.0 MPa and 1.5 MPa.

Four piezometers (UP-02 blocked at 58.5 m and put into use after August 2008, not counted for the time being) are also arranged at the same section, with the numbers UP-01, UP-03 and UP-04, the hole bottom elevations 906.974 m, 899.235 m and 902.180 m respectively, the dam wheelbase -2.5 m, 68 m and 118 m respectively, UP-01 in the core wall, UP-03 and UP-04 in the dam shell material downstream of the core wall.

After inspection, when selecting the original initial value of the osmometer, the frequency mode or resistance ratio and temperature with basically stable readings after embedding in the field are taken as the initial value for calculation, so that the influence of the groundwater level existing in the field during embedding in the construction is ignored and there may be large errors. For this reason, temporarily according to the laboratory calibration data (frequency mode or resistance ratio), regardless of temperature changes (because no data can be found), the calculated water level error is shown in Table 1. For S01 and S02 with large errors, the water level elevation error is superimposed on the original integrated calculated water level to obtain the water level elevation more in line with the actual situation.

| Number | Frequency mode or resistance ratio | Calculation parameter | Water level elevation correction (m) |
|--------|-----------------------------------|-----------------------|-----------------------------------|
|        | Laboratory calibration data       | Initial data of the site |                                      |
| S01    | 3970.70                           | 3684.00               | -0.1105                           | 31.68               |
| S02    | 3901.80                           | 3669.50               | -0.05262                          | 12.22               |
| S03    | 3701.10                           | 3706.80               | -0.13586                          | -0.77               |
| S04    | 4242.45                           | 4249.20               | -0.067325                         | -0.45               |
| S05    | 3976.00                           | 3989.00               | -0.023343                         | -0.3                |
| S06    | 4089.30                           | 4105.20               | -0.023942                         | -0.38               |
| S07    | 4258.65                           | 4279.50               | -0.021859                         | -0.46               |
| S08    | 4304.40                           | 4311.30               | -0.023676                         | -0.16               |
| S09    | 4085.10                           | 4091.30               | -0.022786                         | -0.14               |
3.2. Variation Process Line of Measured Value of Osmotic Pressure at Typical Positions

The process line of the typical position osmometer measurement is shown in Figure 2 and Figure 3.

![Figure 2. Osmometer water level measurement process line.](image)

![Figure 3. S01 water level measurement regression result process line.](image)

3.3. Results Analysis

During the period from September 1, 2017 to August 7, 2018, the reservoir water level is 973.24~995.93 m, with a range of 22.69 m; The seepage pressure level of S01 is 966.87~988.26 m, with a range of 21.39 m; The osmotic pressure level of S02 is 941.20~953.20 m, with a range of 12.00 m; The seepage pressure level of S03 is 947.30~973.22 m, with a range of 25.02 m; The seepage pressure level of S04 is 947.30~972.32 m, with a range of 25.02 m. S01 has a linear correlation with the reservoir water level after the reservoir water level rises to 936.7 m on November 5, 2004, and the regression analysis results are basically all water level components. When the reservoir water level is 970~996 m, S01 seepage pressure water level is 6.0~7.5 m lower than the reservoir water level; S02 has a good correlation with the reservoir water level. After 2006, the linearity of the higher reservoir water level interval is very high. The correlation diagram has no hysteresis curve. The regression analysis results have a small time-effect component, showing the process of unsteady seepage flow in the core wall expanding downstream. There are obvious hysteresis curves in S03 and S04 correlation diagrams on the joint surface of core wall clay and concrete floor. The aging component of regression analysis results is an important or main part, showing the process of unsteady seepage flow in core wall extending downstream and the characteristics of viscosity.

Influenced by the groundwater level in the early stage of S05~S09, the internal seepage pressure gauge of the dam shell material behind the core wall began to rise obviously when the reservoir water level reached 965 m on July 23, 2015, and basically stabilized at 914.26~915.19 m after the reservoir...
water level reached 976m on September 1, 2015, which is no longer related to the upstream water level change.

S10, S12, S11 and S13 in the core wall respond to the changes of reservoir water level from October 22, 2015, January 18, 2016, July 31, 2016 and December 30, 2016 respectively, and then there are obvious hysteresis curves with the correlation diagram of reservoir water level; During the period from September 1, 2015 to August 7, 2018, the seepage pressure level of S10 is 935.11~968.79 m, with a range of 33.6 m; The seepage pressure level of S12 is 964.67~981.75 m, with a variation of 17.08 m; S11 seepage pressure water level is 934.73~943.54 m, with a variation of 8.81 m; The seepage pressure level of S13 is 964.51~965.66 m, with a range of 1.15 m. After 2017, the height of the overflow surface on the downstream side of the core wall will be 965.22 ~ 965.65 m.

The measured water level of UP-01 in the core wall is between S03 and S04 at the same position, and the change process is basically the same. UP-03 and UP-04 in the dam shell material downstream of the core wall are basically consistent with the measured values of S05~S09 in the same position.

4. Conclusion
(1) Foundation curtain: S02, S05~S09, UP-03 and UP-04 data show that the foundation curtain has good seepage prevention effect at present.
(2) Joint surface of clay core wall and foundation slab: S03 and S04 correlation diagrams have obvious hysteresis curves, and the aging component of regression analysis results accounts for an important or major part, showing the process of unsteady seepage flow spreading downstream and the characteristics of viscosity.
(3) The interior of clay core wall: There are obvious hysteresis curves in the correlation diagrams between S10, S12, S11 and S13 inside the core wall and reservoir water level; After 2017, the height of the overflow surface on the downstream side of the core wall will be 965.22 ~ 965.65 m.

References
[1] Wang S W, Gu C S, Bao T F. Observed displacement data-based identification method of deformation time-varying effect of high concrete dams[J]. Science China Technological Sciences, 2018, 61(6):120-129.
[2] Chong-Shi G U, Wang S W, Bao T F. Influence of construction interfaces on dynamic characteristics of roller compacted concrete dams[J]. Journal of Central South University, 2015, 22(4):1521-1535.
[3] Wu Z R, Xu B, Gu C S, et al. Comprehensive evaluation methods for dam service status[J]. Science in China, 2012, 55(8):2300-2312.
[4] Gu C S, Zhao E F, Jin Y, et al. Singular value diagnosis in dam safety monitoring effect values[J]. Science China Technological Sciences, 2011, 54(5):1169-1176.
[5] Wang Z J, Chongshi G U, Liu H C. Assessment Method of Loss Caused by DamBreak Based on GIS and SVM[J]. Journal of Yangtze River Scientific Research Institute, 2008, 25(4):28-32.