UPDATING AND MODERNIZING THE DAM SAFETY MONITORING FACILITIES OF THE CHARSEN RESERVOIR

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ABSTRACT

This paper analyzed the problems present at the dam safety monitoring facilities of the Charsen reservoir. Based on the technical specifications and according to advanced research results for earth-rockfill dam safety monitoring, the programme for modernizing the dam safety monitoring facilities of the Charsen reservoir was brought forward. This programme will provide a guarantee for improving the reservoir dam safety level and maximize its social and economic benefits.
1. INTRODUCTION

The Charsen reservoir is located in the middle reaches of the Taoer River, a tributary of the Nenjiang River, in the area of Keyouqianqi County, in the Inner Mongolia Autonomous Region. The dam is 1.7 km north of the town of Charsen, and 32 km from the city of Ulanhot (Wulanhaote). The Charsen reservoir is a large type-I reservoir and is the only key project controlled by the programme in the upper reaches of the Taoer River; its functions are flood control, irrigation, power generation and it can also be used for aquaculture. The reservoir is composed of a rockfill dam with a loam core wall, spillway, sluice tunnel and power station. The total reservoir storage capacity is $12.53 \times 10^8$ m$^3$, the dam height is 40.0m, the width of the dam crest is 6.0m, and the length of the dam crest is 1,712m. Seven counties downstream of the reservoir are protected, including 350,906 acres of farmland, 802,306 acres of grassland, approximately two million of the local population and their property, as well as four railways, three highways and two oil fields.

Since the reservoir was impounded, it has played a big role in flood control and improving the local ecological environment. According to statistics, in 1993 the flood peak rate was reduced by 74%, and the flood control benefits totaled 140 million RMB; in 1998 the flood peak rate was reduced by 97.4% and the flood control benefits totaled 7.628 billion RMB. In 2004 the reservoir made an emergency supply of $0.8x10^8$ m$^3$ water to the Xianghai wetland and in 2011 another emergency supply of the same volume of water; these measures were greatly beneficial for improving the Xianghai wetland ecological environment, and the sustainable development of the rare birds' habitat.

So far, the reservoir has been operating for 20 years. In May 2011 the Nanjing Hydraulic Research Institute completed a dam safety appraisal report; in June 2011 the dam safety status was classified at grade III through examination and evaluation by an expert group in a special appraisal meeting, which was organized by the Songliao Water Resources Commission (SLW), Ministry of Water Resources (MWR). In July 2011 the dam safety management center of the MWR approved the classification conclusion through the official document "The verification of the dam appraisal results of the Charsen reservoir safety status which was classed at grade III" (letter by MWR No. 2041 [2011] re the dam). Therefore, we need to take measures to eliminate danger and reinforce the reservoir; one of the important measures is to update and improve the facilities for dam safety monitoring.

2. THE DAM SAFETY MONITORING SYSTEMS

There are two main kinds of dam safety monitoring in the Charsen reservoir, which are deformation monitoring and seepage monitoring.

2.1 DEFORMATION MONITORING

For measurement purposes, 29 monitoring points were set up for dam surface vertical displacement monitoring and level displacement monitoring. These include: 17 monitoring points which were set up on the top of the dam with an interval distance of 100 m, called line A; four monitoring points which were set up in the berm
downstream of the dam, called line B; 4 monitoring points which were set up downstream of the dam at an elevation of 341.1 m, called line C; and four monitoring points which were set up on the upstream of the dam at an elevation of 367.0 m, called line D.

A settlement gauge and inclinometer are used for measuring vertical displacement and level displacement of the interior dam, and two observation boreholes are located at Pile No 0+360 m and Pile No 1+442 m respectively.

Lines A and D, for surface vertical displacement monitoring, have the working base points AD (E) and AD (W), located in the east and west of the dam respectively; for lines B and C, also for surface vertical displacement monitoring, their working base points are BC (E) and BC (W), which are located in the east and west berms of the dam respectively.

Level displacement monitoring is carried out by the four collimation lines, Each line has two base points, which were set up on the rock mass in the east and west of the dam respectively, and therefore there are a total of eight base points.

In addition, 10 surface vertical displacement monitoring points were set up on the side walls of the spillway, and their working base points were named YHD, which was set up behind the spillway pump house.

2.2 Seepage Monitoring

In 1991 65 observation boreholes were installed in 11 sections of the dam for seepage monitoring. There were 45 observation boreholes installed in the dam body, 15 observation boreholes installed in the dam foundation, and five observation boreholes installed in both sides of the dam.

In April 2004 one section with five observation boreholes was added for dam seepage monitoring, including two observation boreholes installed in the core wall; three observation boreholes were installed in the sandy gravel stratum.

So far, 70 observation boreholes have been installed for dam seepage monitoring.

3. Major Problems of the Safety Monitoring Facilities at the Present

- The existing facilities for dam safety monitoring are aging; most of them have been seriously damaged due to the effects of freezing and thawing. Furthermore, the collimation line spaces are too long, and therefore cannot meet the accuracy requirements of level displacement monitoring.

- The three-dimensional coordinatographs, which had been used for level displacement monitoring, were out of repair and therefore the inverted perpendicular was no longer able to be used for checking the working base points.

- Because the piezometer tube protector was buried at a shallow level in the road
surface of the dam, this has often made the protective device vulnerable to broken welded joints and to deformation, as well as being difficult to open, due to long periods of being rolled over by vehicles. In addition, the protector is located at a lower point of the dam crest, where it is easy for rainwater and snowmelt runoff to get in.

- Regarding the facilities for seepage monitoring, the electric cables between the outlets of the piezometer tubes to the MCU were aging and seriously rusted, that affects signal transmission.

- Because upstream of the dry-laid stone revetment was grouted by fine stone concrete, this results in the monitoring points being concreted into the revetment. This situation leads to distortion in the measurement of deformation monitoring.

- The existing safety monitoring system has a faulty design, because there were no stress monitoring facilities set up at the gate pier or the weir of the spillway.

4. SAFETY MONITORING DESIGN

4.1 THE PRINCIPLE OF THE DESIGN

Considering the development in dam safety monitoring at home and abroad, the following principles should be adopted in the design of the safety monitoring system:

- The necessary repair and upgrade works should be carried out based on the existing safety monitoring system;

- The scale of the monitoring work should match with the project level and serve the needs of the safety assessment.

- New and updated monitoring equipment should be closely combined with the specific engineering conditions of the dam and at the same time be able to produce data that is compatible with the original monitoring data comparison and analysis.

- The main technical indicators of the monitoring equipment should meet the requirements of the current national standards for dam monitoring instruments; the instrument embedment should be tested; calibration and waterproofing of the cable joint should be carried out before burial work; and the information about the cable scheme should be timely recorded on forms and in plans.

- The new position of the monitoring sections should refer to the position of the original monitoring sections, and be placed where geological conditions are poor and the geological structure is complex and weak. Also the monitoring should still perform its necessary functions even under rough and harsh environmental conditions, where a special monitoring station may be set up if necessary.

- The collimation line target’s shape, structure, size and color have an important influence on the accuracy of the observation. Therefore it should be well designed and meet the following standards: pattern symmetry, no measuring phase differences, be eye-catching, easy to install and with an appropriate reference area (both sides of the crosshair have sufficient area for reference).
- For achieving the monitoring goals, one of the important pre-requisites is to select the proper monitoring equipment and facilities. The qualifications below can be used for equipment or facility selection:

- Selecting the monitoring instruments should be based on the size and importance of the project and the service life, and determined by the item being monitored, geological conditions and structure, construction and the technology used during the project.

- The selected instruments should: have high reliability, be able to adjust to the installation and operation environment, have little sensitivity to disturbance, and be able to maintain a good performance status.

- The instrument (or apparatus) should have the following characteristics: a high level of accuracy, durability, and calibration consistency, and be reusable.

- Instruments or equipment should be selected that have been successfully applied in other similar projects.

- The product selected should have good credibility and after-sales service.

- The selected instrument and equipment should be economic and not costly to use and be easy to install, maintain and test, and it should be easy to realize automatic monitoring.

4.2 Surface Deformation Monitoring

4.2.1 Vertical Displacement Monitoring

Taking into account the actual conditions of the dam reconstruction and the original monitoring facilities network, the vertical displacement monitoring in the new plan will still use the precise leveling method with DNA03 precision electronic level and ancillary digital level staff.

The original sixteen vertical displacement monitoring points that are located in the downstream side of the dam crest road will be restored. New monitoring points will be set up along the axis of the dam at the same sites or nearby the sites of the original monitoring points, so that the original data can continue to be used in the new monitoring system.

The facilities of the 12 vertical displacement monitoring points (lines B, C and D, each of which have four points) and seven working base points must be updated, and the rusty protective caps must be replaced.

At each spillway pier one vertical displacement monitoring point will be set up, in total five points. The plan is to restore the spillway level working base points, and on each side of the spillway a group of working base points (two points) will be set.
4.2.2 Level Displacement Monitoring

In consideration of the actual conditions of the dam reconstruction and the original monitoring facilities network, the level displacement monitoring will still use the collimation line method. Collimation line monitoring uses the minor angle method. In order to increase the accuracy of the collimation line monitoring and to reduce the workload, a Leica electronic tachymeter total station that is produced in Switzerland and ancillary equipment will be introduced. The functions of these devices are automatic target recognition and fast tracking.

According to the dam crest demolition and design scheme, with regard to the original monitoring point network, the level displacement monitoring points that are located on the downstream side of the dam crest will be restored. Each of these monitoring points will have an interval distance of 100 m. There are 16 monitoring points on the dam crest, along the dam axis, located as close to the original monitoring points of line A as possible, in order to link up with the original monitoring data for data analysis in future.

A collimation line checking datum mark is set up on each of the extension lines of the working base points. The right bank checking datum mark is set up at the massif; the left bank checking datum mark is substituted by the inverted perpendicular, because there are no suitable places due to the dam structure and topography. The checking datum mark is located at the same place as the working base points.

An optical coordinator and a telemetric coordinator will be adopted in the inverted perpendicular method for conventional observation and automatic observation respectively. The telemetric coordinator should have an independent MCU and the MCU will transmit data by wireless communication equipment to an automatic data acquisition center that is located in the Charsen Reservoir.

Because the collimation line above the dam crest is as long as 1,800 m, new working base points (or if there is no suitable place to set them up then this can be carried out instead by monitoring points) will be added in the middle of every longitudinal row of monitoring points, in order to improve the observation accuracy and in line with the design code. In addition, new checking datum marks to working base points will be built at the site of Pile 0+206 m, Pile 0+706 m and Pile 1+206 m on the downstream side of the dam.

The equipment for the 12 original level displacement monitoring points (each line of B, C and D with 4 points respectively) and 12 base points (or checking datum mark) will be updated, and any rusty protection covers will be replaced.

4.3 Seepage Monitoring

Seepage monitoring includes dam foundation uplift monitoring and seepage around the dam monitoring, and so on.

In order to wholly understand the problems existing in the project, a comprehensive
inspection of all the cable lines has to be conducted. Also, aging cables, pipes and the cables must be replaced.

There are approximately 21 piezometers that need to be changed and added. All the piezometer tubes must be cleaned and any rusty or damaged piezometers replaced. Preliminary estimates are that 10 piezometers in total need to be changed; because the original piezometer tubes on the original dam crest were damaged during the process of the anti-seepage construction work, a core hole needs to be reconstructed at the dam crest for installation of the piezometer tubes. There are seven piezometers that need to be inserted into the tubes. According to the spillway reformation scheme, four piezometers will be set up at the foundation of the spillway to monitor the pressure of the seepage flow under the sluice floor slab. The instruments’ cables will be connected to the MCU that is set in the hoist chamber of the dam crest.

4.4 Monitoring the Concrete Stress, Steel Stress and Thermal Stress of the Spillway Pier

The monitoring of concrete stress, steel stress and thermal stress are new design items in the new spillway scheme in the project to eliminate danger and strengthen the reservoir.

Strainometer groups, zero stress-strain meters, rebar stress meters and thermometers have been designed to be installed at monitoring sections on the spillway pier for monitoring concrete stress, steel stress and thermal stress.

4.4.1 Monitoring the Concrete Stress of the Spillway Pier

For monitoring the concrete stress of the spillway pier, two strainometer groups will be installed in a monitoring section where there is a concentration of stress. A zero stress-strain meter will be installed 1.5 m distant to a strainometer group. There will be in total two of these strainometer groups and two zero stress-strain meters.

4.4.2 Monitoring the Steel Stress of the Spillway Pier

For monitoring the sections where there is steel stress, 10 rebar stress meters will be set up at different altitudes of the sector-shaped steel in the monitoring section, and rebar stress meters will be set up at the two sides bearing the foundation of the pier arch gate, in total 12 rebar stress meters.

4.4.3 Monitoring the Thermal Stress of the Spillway Pier

Because monitoring of the temperature, concrete stress and steel stress use the same monitoring section in the gate pier, and a strainometer can also be used for monitoring the temperature, therefore no thermometers have been set up at the place where there is a strainometer. In total 21 thermometers will be set up at the gate pier and weir of the spillway.
Core holes will be constructed at different altitudes at the foundation of the dam and each hole will contain a thermometer for monitoring temperature.

4.4.4 Newly Added Automatic Monitoring Equipment

51 new items of equipment and apparatus will be added to the automatic monitoring system; their data is acquired by the MCU in the monitoring stations, and communicated with the original automatic monitoring system by a radio signal.

Two monitoring stations need to be constructed: station No 1 will be set up in an observation room which is located at Pile No 0+506 mc, and station No 2 will be set up in the hoist chamber on the pier.

The signal of the telemetric coordinator is captured by an MCU that will be installed in station No 1. The signals from the equipment and apparatus that will be displayed in the pier are captured by two MCUs that will be set in station No 2.

5. CONCLUSION

"Little strokes fell great oaks.” The status of a hydraulic structure in the process of construction and in operation also changes, due to outer loads and all kinds of influencing factors. Moreover, this kind of change is often hidden, slow, and not easy to detect. Accidents or loss can be avoided if we can get relevant information before the accident, analyze the information and make judgments, in order to take timely and effective measures.

Therefore, updating and renovating the safety monitoring system, in addition to timely analysis of the monitoring data using modern technology, and passing on these results to the management, are an important guarantee for the safe operation and maximum efficiency of the reservoir.

Safety monitoring is the “eyes and ears” for water project management and it is also an important fundamental task for dam safety management. “Safety monitoring is a duty with great responsibility, and this is inscribed on the heart of water conservancy workers”.

6. KEY WORDS

Charsen reservoir; dam safety monitoring facility; deformation monitoring; seepage monitoring; stress monitoring.