Surface Deformation Monitoring for a Concrete-face Rockfill Dam

Yutang Ding¹*, Wenang Hou¹ and Xiaomei Li¹

¹Geotechnical Engineering Department, Nanjing Hydraulic Research Institute, Nanjing, Jiangsu, 210024, China

*Corresponding author’s e-mail: ytding@nhri.cn

Abstract: Deformation monitoring is very important in the management of water dams. For rockfill dams, the surface deformation in run-time stage can be tiny and the true values can be easily covered by measuring errors when using traditional methods. In this paper, the Tension Wire Alignment System and the Hydrostatic Leveling System are employed to measure the surface deformation of Zeya dam. The collected data indicates the good performance of the systems. The deformation patterns are then analyzed based on the monitoring data.

1. Introduction

During the past few decades, numerous water dams have been built in China in order to support the process of urbanization. The concrete-face rockfill dam, famous for its low cost, is one of the most important dam types in China. Though the concrete-face rockfill dam has experienced great progress during the past few decades[1], safety accident can happen and bring huge loss for people’s lives as well as the economy[2]. Thus the safety monitoring of the concrete-face rockfill dams is by no means a meaningless work.

The concrete-face plays a key role in the anti-seepage system as it prevents the seepage water coming into the rockfill zone and then causing irreversible wetting deformations. Since the concrete-face lies directly on the upstream surface of the dam body, any deformation of the dam body will impose external loads onto the concrete-face. Thus the deformation of the dam body has a strong influence on the dam safety and is listed as an essential part in designing safety monitoring systems[3,4].

In the construction stage, the deformation can be very large and the maximum subsidence may approach 0.3-0.5% of the total height. However, in the run-time stage, the deformations are relatively tiny as the deformations are mainly caused by the rockfill creep. To monitor the surface deformation, engineering surveying methods are often employed with the help of the total station and the digital leveling instrument. This approach, however, suffers from low efficiency as it takes a lot of time and has strict requirements in weather. What’s more, the accuracy of the measured values depends greatly not only on the equipment but also on the operators. Then the true displacement information in run-time stage can be easily covered by the measuring errors.

The Tension Wire Alignment System (for measuring the horizontal surface displacement) and the Hydro-static Leveling System (for measuring the vertical surface displacement) are frequently used in concrete dams to monitor the surface deformation and have achieved satisfying results[5,6]. Few attempts, however, have been made in using these systems in rockfill dams. In this paper, an application of these systems in a rockfill dam is introduced. In what follows, the working principles of...
the systems are briefly illustrated. Then the application of the two systems in Zeya Dam is introduced. Next the measuring data of the surface deformation is organized and presented. Lastly, the performance of the measuring systems is evaluated and the surface deformation features of the rockfill dam are concluded.

2. The working principles of the measuring system

2.1. The Tension Wire Alignment System
The Tension Wire Alignment System can be illustrated with figure 1 and figure 2. All the measuring points are aligned. An alloy wire (the tension wire) is stretched with the fix point and the tension point. To reduce the effect of line weight, the floating body is added. When the horizontal deformation takes place in a measuring point, the displacement will be detected by the sensor. The sensor will translate the deformation into electronic signals and the signals are then transferred to the computer system. The measuring scale can be ±20mm (“+” means the downstream direction, “-” means the upstream direction). The measuring accuracy can reach 0.1mm.

![Figure 1. The sketch of the Tension Wire Alignment System.](image1)

2.2. The Hydro-static Leveling System
The Hydro-static Leveling System can be illustrated in figure 3 and figure 4. Using the principle of the connected vessels, the height of the liquid surface will change when vertical displacement arises in a measuring point. Then the deformation will be detected by the electronic sensor devices and translated into signals. The signals are then transferred to the computer system. The measuring scale can be 50mm. The measuring accuracy can reach 0.1mm.

![Figure 2. The sketch of the measuring point.](image2)
3. Surface deformation monitoring in Zeya Dam

Zeya reservoir is located in Wenzhou, Zhejiang Province, China. Zeya dam is a concrete-face rockfill dam and is built in the year of 1998. The height of the dam is 78.8m and the length of the top is 313.5m. The water level changes greatly (over 30m) in a single year. Thus the water pressure imposed on the dam body varies significantly and the deformation patterns need to be grasped to ensure the dam safety.

To monitoring the surface deformation in run-time stage, the Tension Wire Alignment System and the Hydro-static Leveling System are employed to monitor the horizontal displacement and vertical displacement respectively. The design of the monitoring system can be illustrated in figure 5. The
measuring points of the Tension Wire Alignment System are TP1-TP7 while the measuring points of the Hydro-static Leveling System are LD1-LD7. All the measuring points are located on the top of the dam. The construction of the above measuring points was finished in 2016.

Figure 5. The sketch of the measuring point location.

4. Data collection and analysis

All the measuring points are connected with the automatic measuring system where deformation data is collected and transferred to the computer system per day. To have a better understanding of the deformation patterns, the water level in 2018 is also presented in figure 6. The horizontal and vertical deformations in 2018 measured by the automatic measuring system are shown in figure 7 and figure 8.

As can be seen from figure 6, the water level undergoes a significant rise since May as a result of rain falls. The horizontal displacement shows an increasing tendency in the rainy season as can be seen in figure 7. The measured deformations in TP3, TP4 & TP5 exhibit significant change. The maximum displacement is around 7mm (downstream direction) while the minimum displacement is over -4mm (upstream direction). Meanwhile, the displacements in TP1 & TP7 remain relatively steady and the values are close to 0. The above measured data reveals that certain horizontal deformation exists in run-time stage and the amplitude of the fluctuation can reach 11mm for Zeya dam. The horizontal deformation features have strong connection with the water level and the increase of deformation in downstream direction maybe attributed to the increase of the water pressure.

The vertical displacement is shown in figure 8. Similarly, the vertical deformation concentrates on the central area. The measuring points (LD3, LD4 & LD5) near the central area have the largest subsidence (around 10-15mm). The subsidence of the measuring points (LD1 & LD7) near the two sides of the dam is just around 5-7mm. Though the amplitude of the fluctuation for one measuring point can reach 5mm, no obvious relationship between the vertical displacement and the water level is observed. The vertical displacement remains relatively steady while the water level changes greatly. The data indicates that the water level have no significant influence on the vertical deformation during the run-time stage.
Figure 6. Water level of Zeya reservoir in 2018.

Figure 7. Horizontal displacement of Zeya dam in 2018.
5. Conclusions
To measure the deformation patterns of the rockfill dam in run-time stage, the Tension Wire Alignment System and the Hydro-static Leveling System are employed. The collected data reveals that the above systems are capable of measuring tiny deformation for the dams in run-time stage. The results show that the horizontal displacement is influenced by the water level while the vertical displacement remains relatively steady.

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