The arrangement of deformation monitoring project and analysis of monitoring data of a hydropower engineering safety monitoring system

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Abstract. The safety monitoring is very important in the operation and management of water resources and hydropower projects. It is the important means to understand the dam running status, to ensure the dam safety, to safeguard people's life and property security, and to make full use of engineering benefits. This paper introduces the arrangement of engineering safety monitoring system based on the example of a water resource control project. The monitoring results of each monitoring project are analyzed intensively to show the operating status of the monitoring system and to provide useful reference for similar projects.

1. An overview
A hydro-junction project consists of the main dam, the flood discharge and diversion tunnel, the diversion hydropower system, the spillway, the high side slope of the right bank and the water supply and irrigation hole. The main dam consists of the anti-seepage wall, the asphalt core wall, the filling damming dam area, the rock filling dam and other auxiliary facilities. The spillway and diversion tunnel are mainly composed of the main hole, the opening and closing machine room of the import and export and corresponding auxiliary projects. The diversion hydropower system consists mainly of the diversion hydropower hole, the diversion hydropower sub-hole, the ground plant and corresponding auxiliary projects. The high side slope is mainly composed of the side slope behind the plant, the side slope of t the spillway and diversion tunnel and the side slope of the spillway. The main monitoring projects of the safety monitoring system are deformation monitoring, seepage monitoring, environmental monitoring and strong earthquake monitoring. Deformation monitoring is the most intuitive monitoring project, which is discussed in this paper detailed.

2. Monitoring project and system arrangement
2.1. Internal deformation monitoring of dam body
The monitoring instruments of the horizontal displacement of the dam are the soil displacement meter and the hole with clinometers. The monitoring instruments of vertical displacement in the dam are stringed sediment meter and electromagnetic subsidence hole.
2.2. Dislocation monitoring
The dislocation monitoring instrument of the joint of the concrete anti-seepage wall and the asphalt core wall and between the rock-fill material and the asphalt core wall is the dislocation meter.

2.3. Deformation monitoring of dam body surface
The horizontal displacement of dam body surface is observed by the high precise GPS, and the vertical displacement of dam body surfaces observed by the leveling point.

2.4. Deformation monitoring of the diversion hydropower system
The different depth displacement monitoring of the tunnel surrounding rock of the diversion hydropower system is observed by the multi-point displacement meter. The deformation monitoring of the degree of opening of surrounding rock and lining is observed by the seam measurement meter.

2.5. Deformation monitoring of the flood discharge and diversion tunnel
The deformation monitoring of the degree of opening of surrounding rock and lining of the flood discharge and diversion tunnel is measured by the seam measurement meter.

2.6. Deformation monitoring of side slope
The monitoring of the rock body displacement is measured by multi-point displacement meter and the hole with clinometers. The displacement includes the side slope behind the plants, the joint of plants and the side slope of the flood discharge and diversion tunnel, the outlet side slope of the flood discharge and diversion tunnel and the outlet side slope of the flood discharge tunnel.

The surface deformation monitoring is measured by GPS and leveling observation points.

The position and quantity of deformation monitoring instruments are shown in table 1.

| serial number | monitoring project | name of monitoring instruments | position | quantity |
|---------------|-------------------|--------------------------------|----------|----------|
| 1             | Internal deformation monitoring of dam body | the soil displacement meter | DL.0+331.00m, DL.0+522.00 and EL.4052.00m and EL.4076.00m | 24       |
|               |                    | the hole with clinometers     | DL.0+331.00m, DL.0+522.00 and EL.4052.00m and EL.4076.00m | 18       |
|               |                    | stringed sediment meter       | DL.0+331.00m, DL.0+522.00 and EL.4052.00m and EL.4076.00m | 24       |
|               |                    | electromagnetic subsidence hole| DL.0+331.00m, DL.0+522.00 and EL.4052.00m and EL.4076.00m | 18       |
| 2             | Dislocation monitoring | the dislocation meter | DL.0+331.00m, DL.0+522.00 and EL.4052.00m and EL.4076.00m | 16       |
| 3             | Deformation monitoring of dam body surface | GPS | EL.4052.00m, EL.4076.00m, EL.4100.00m | 27       |
|               | Deformation monitoring of the diversion hydropower system | the leveling point | DT.0+060.00m | 3 sets   |
|               | Deformation monitoring of the flood discharge and diversion | the multi-point displacement meter | DT.0+060.00m, DT.0+294.04m, DT.0+328.82m, TDB N0.30+82.00m, TDB N0.1 0+55.00m | 12       |
| 4             |                     | the seam measurement meter    | DT.0+120.61m, DT.0+610.00m | 8        |

Table 1. The name, position and quantity of deformation monitoring instruments.
3. Monitoring data analysis

3.1. Internal deformation monitoring of dam body

3.1.1. Horizontal displacement. The initial value of the observation was obtained on 28 April 2012 by the 5-point soil displacement meter located at DL.0+331.00m, EL.4052.00m. At present (30 July 2016), the cumulative change of each measuring point is between 1.39mm~4.33mm. Over time, the displacement of EL 4052.00m high range soil to the asphalt core wall increased gradually and stabilized gradually after July 2016. The general trend is that the further the core wall, the greater the displacement is. The process line of horizontal displacement monitoring values observed by the soil displacement meter located at DL.0+331.00m, EL.4052.00m is shown in figure 1.

![Figure 1](image-url)

**Figure 1.** The process line of horizontal displacement monitoring values observed by the soil displacement meter located at DL. 0+331.00m, EL.4052.00m.

The initial value of the observation was obtained on 2 August 2012 by the 3-point soil displacement meter located at DL.0+331.00m, EL.4076.00m. At present (30 July 2016), the cumulative change of each measuring point is between 0.20mm~1.16mm. Over time, the displacement of EL 4076.00m high range soil to the asphalt core wall increased gradually and stabilized gradually after January 2016. The process line of horizontal displacement monitoring values observed by the soil displacement meter located at DL.0+331.00m, EL.4076.00m is shown in figure 2.
Figure 2. The process line of horizontal displacement monitoring values observed by the soil displacement meter located at DL.0+331.00m, EL.4076.00m.

There were 6 survey holes at DL.0+331.00m. Due to the interference and measuring pipe extended, the measurement time is less and some measuring holes are not buried properly. The normal observation cannot go. The IN2-5 hole got the initial measurement value on 21 June 2013. The cumulative displacement of the orifice to the downstream direction is 2.91mm. The distribution of displacement measurement values of the oblique hole IN2-5 at DL.0+331.00m, EL.4076.00m is shown in figure 3.

Figure 3. The distribution of displacement measurement values of the oblique hole IN2-5 at DL.0+331.00m, EL.4076.00m.

3.1.2. *Vertical displacement*. The initial value of the observation was obtained on 24 August 2012 by the 5-point stringed sediment meter located at DL.0+331.00m, EL.4052.00m. At present (30 July 2016), the cumulative sediment change of each measuring point is between 344.18mm–370.25mm and the sediment of each measuring point stabilized gradually. The process line of sediment monitoring at DL.0+331.00m, EL.4052.00m is shown in figure 4.
Figure 4. The process line of sediment monitoring at DL 0+331.00m, EL.4052.00m.

The initial value of the observation was obtained on 19 July 2013 by the 3-point stringed sediment meter located at DL.0+331.00m, EL.4076.00m. At present (30 July 2016), the cumulative sediment change of each measuring point is between 48.05 mm ~ 54.60 mm and the value of each measuring point grew slowly. The process line of sediment monitoring at DL. 0+331.00m, EL.4076.00m is shown in Figure 5.

Figure 5. The process line of sediment monitoring at DL. 0+331.00m, EL.4076.00m.

3.1.3. Dislocation meter. Through continuous monitoring between asphalt core wall and filling body dislocation, at present (July 30, 2016), the dislocation value by the dislocation meter of the downstream side changes from 7.60 mm to 0.35 mm cumulatively. The change is small and stable gradually. The process curve of dislocation of asphalt core wall and gravel filling body is shown in figure 6.

Figure 6. The process curve of dislocation of asphalt core wall and gravel filling body.
3.1.4. Sediment magnetic ring. There were 6 sediment observation holes at DL. 0+331.00 m. The dam foundation is the interface of subsidence holes (tubes). Magnetic rings were arranged according to 10 m separation distance below and 2 m separation distance above. The sediment results of each observation hole relative to the fixed point at the bottom are shown in table 2.

| Number of observation hole | Number of dam horizontal pile | Initial data (m) | Observation depth (m) | Relative sediment (mm) | Storage period sediment (mm) |
|---------------------------|-------------------------------|------------------|-----------------------|------------------------|----------------------------|
| IN1-1                     | 0-044.00                      | 2012-8-25        | 81.46                 | 271.7                  | 49.5                       |
| IN1-2                     | 0-008.50                      | 2012-8-25        | 61.67                 | 111.9                  | 48.7                       |
| IN1-3                     | 0+000.00                      | 2012-8-25        | 56.58                 | 92.7                   | 46.2                       |
| IN1-4                     | 0+020.00                      | 2012-8-25        | 200.69                | 300.3                  | 51.3                       |
| IN1-5                     | 0+053.10                      | 2012-9-16        | 47.36                 | 118.3                  | 47.6                       |
| IN1-6                     | 0+105.50                      | 2012-8-25        | 140.96                | 361.9                  | 45.8                       |

3.2. Surface deformation monitoring
The surface deformation monitoring of dam body is monitored by GPS measurement point. The measurement points are arranged at the top of the dam (EL. 4100m), EL. 4076m berm and EL. 4052 m berm, with eight measurement points each elevation. The GPS monitoring system of the dam was completed in early November 2013, and the monitoring results show that the horizontal displacement has the characteristics of more displacement at the middle of the dam (to the lower reaches) and less displacement at the both end. The horizontal displacement of the BT22 measurement point at EL.4052m berm in the central part of the dam was about 100mm, and the horizontal displacement of the BT14 measurement point at EL. 7076m berm was about 120mm. The horizontal displacement of the BT10 measurement point at EL. 4076m berm of the left dam end was about 40mm. The vertical displacement also shows the characteristics of more displacement at the middle and less displacement at the both end. The higher elevation, the higher the vertical displacement (settlement) is. The vertical displacement of the BT22 measurement point at EL. 4052m berm in the central part of the dam is about 200mm, and the vertical displacement of the BT14 point at the EL.7076m berm is about 240mm. The vertical displacement of the BT10 measurement point at EL.4076mberm of the left end was about 65mm. The horizontal displacement of the dam has a great correlation with the reservoir water level, and the horizontal displacement changes with the fluctuation of the water level. Under the condition of stable water level, horizontal displacement has stabilized gradually and has a tendency to decrease gradually. With the completion of the consolidation of the dam, the growth of vertical displacement gradually converges to a stable state. The corresponding process lines of horizontal displacement, vertical displacement and reservoir water level of BT10 measurement point, BT14 measurement point and BT22 measurement point are shown in figure7-figure9.


Figure 7. The process line of horizontal displacement, vertical displacement and reservoir water level of BT10 measurement point.

Figure 8. The process line of horizontal displacement, vertical displacement and reservoir water level of BT14 measurement point.

Figure 9. The process line of horizontal displacement, vertical displacement and reservoir water level of BT22 measurement point.

4. Conclusion
During 3 years from the construction of project to normal operation, the cumulative horizontal displacement of the dam soil displacement meter relative to asphalt core wall is between -2.24 mm and 16.56 mm. The cumulative displacement of the inclined hole relative to the bottom of the hole toward the water flow direction is between 12.62 mm and 18.39 mm. The horizontal displacement of GPS toward the direction of the flow is between 3 mm and 10 mm. The cumulative sediment of the
sediment magnetic ring relative to the bottom of the inclined hole is between 92.70mm and 433.67mm, and the level monitoring settlement is between 38.90mm and 278.20 mm.

All of the deformation monitoring projects obtained the base value in time according to the specification, and obtained the continuous security monitoring data as long as possible. The deformation monitoring data was obtained timely during the filling construction stage and the impoundment loading period. It provides accurate information in time to control sediment and seepage in the process of construction, and it helps adopting reasonable construction measures to fill the dam. The monitoring system provides accurate data timely and plays an extremely important role in analyzing and evaluating the working state of dam buildings and their basic processing.

Reference
[1] SL551-2012 Technical specification for earth-rockfill dam safety monitoring[S].Beijing: China Water Power Press, 2012.
[2] Dam safety monitoring center of the National Electric Power Regulatory Commission. Safety monitoring manual for geotechnical engineering [M]. third edition. Beijing : China WaterPower Press, 2013: CHAPTER 7.
[3] Wang Jigang,Tang Guoqing,Tao Youqi. Practice of safety monitoring management during construction period of large-scale hydropower project[J].Northwest Hydropower, 1-5(2017-03-14).
[4]Wei Jiandong. The development and Prospect of modern deformation monitoring technology [J]. surveying and Mapping Science, 2007, (06): 10-13+204.
[5]Huang Zhipeng, Dong Yanjun, Liao Nianchun,etc. Analysis of the deformation monitoring of the left bank of Jinping No. 1 Hydropower Station on working, [J]. geotechnical mechanics, 2012,33 (S2): 235-242.
[6]Gan Xingyun. Safety monitoring and control of dam engineering in water conservancy and hydropower project [J]. China high-tech enterprises, 2015, (27): 126-127.