Analysis of long-term temperature monitoring data of a RCC dam in alpine region

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Abstract. Based on the monitoring data of a roller compacted concrete dam in an alpine region, the paper analyses the relationship between environmental factors and reservoir water temperature, dam body temperature and foundation temperature, and the changing law, so as to explore the actual internal temperature state of the dam, and provide useful technical support for the long-term safe operation of the dam.

1. Project profile
Located in the northern border area of China, the project is a large water conservancy project. The total storage capacity of the hub reservoir is 2.419 billion m$^3$, and the regulated storage capacity is 1.918 billion m$^3$. The normal water level of the reservoir is 739m and the dead water level is 680m. The power station has an installed capacity of 140MW and an annual generating capacity of 519 million KWh. The water control project consists of a roller compacted concrete gravity dam, overflow surface hole, flood discharge hole, drainage bottom hole, power generation and diversion system, power plant and auxiliary dam. The main dam of the hub adopts a full-section RCC dam with a length of 1489m, the highest dam height of the main dam is 121.50m, and the highest dam height of the auxiliary dam is 14.00m. The dam site area has high latitude, full sunshine and broad annual range of temperature.

Temperature is one of the important factors affecting the working behavior of a dam, the monitoring data during the construction period is an important basis for the construction quality control and guidance of the construction schedule, and during the water storage and operation period is an important index to grasp and analyze the displacement and stress changes of the dam. The temperature variation of dam concrete has great influence on dam deformation and stress. In order to explore the influence of concrete hydration heat, water temperature, air temperature and solar radiation on dam body temperature, typical dam sections were selected for temperature monitoring. The main monitoring sections were block dam section 35#, overflow dam section 29#, right bank platform dam section 57#, and auxiliary monitoring section dam section 25#. Temperature monitoring projects include reservoir water temperature, RCC temperature inside the dam body, dam body surface temperature and dam foundation temperature. The arrangement of temperature gauge in typical section is shown in figure 1.
Figure 1. The arrangement of temperature gauge in typical section.

2. Environmental factor analysis

The analysis of environmental factors mainly includes two factors: environmental temperature and water level. Environmental temperature is the "source" affecting other temperature changes of the dam body[1]. Meanwhile, in alpine areas, the reservoir water and ice sheet play a role of thermal insulation of the dam body due to broad annual range of temperature.

2.1. The temperature monitoring

Due to the limited meteorological data at the site of the project, only the temperature data collected from October 2013 to May 2015 were analyzed. Figure 2 is the process line of monitoring temperature. The line shows that only in 2014, a complete temperature change process was recorded.

Figure 2. The process line of monitoring temperature.

In 2014, the highest average daily temperature in summer was 30.73°C, which occurred on July 13. The lowest average daily temperature in winter is -27.96°C, which occurred on January 6. The annual variation is 58.70°C. Refer to relevant data, the summer in the area is generally from mid-may to mid-September, winter is from early November to late March.
2.2. Reservoir level monitoring
The time range of upstream reservoir water level monitoring data is from September 2008 to October 2015, and the time range of downstream reservoir water level monitoring data is from April 2011 to October 2015. Figure 3 shows the process line of upstream reservoir water level change, and figure 4 shows the process line of downstream water level change.

![Reservoir water level change](image)

**Figure 3.** The process line of upstream reservoir water level change

On September 25, 2008, the project entered the first impoundment stage of the diversion tunnel and the reservoir water level fluctuated and rose all the time. In early April 2010, spring flood water was used to store water, and on August 27, 2010, the highest water level reached 722.8m. After that, the spring snow melt and freezing thaw are used to store the water to the high water level every year, and the water level drops to the low water level before the summer flood season, with an annual variation of 10-20m.

![Downstream water level change](image)

**Figure 4.** The process line of downstream water level change

There is little change in the water level downstream, and the highest water level come at the end of May or early June of each year. The highest water level in previous years ranges from 643.51m to 646.42m. The lowest water level occurs between October and December of each year, and the lowest water level is between 641.02m and 642.09m. The annual variation ranges from 2.31m to 5.25m.

3. Reservoir water temperature
Reservoir water temperature is related to the natural characteristics of the reservoir location (including dam area temperature, solar radiation, etc.), reservoir characteristics and reservoir operation mode. The temperature of the reservoir is monitored by embedding the temperature gauge in the concrete 5cm-10cm away from the surface. The monitoring points are distributed along the elevation in the upstream of the key monitoring sections 25# dam section, 29# dam section, 35# dam section and 57# dam section.
The temperature of the reservoir water is analyzed using the observed data from 2017 after the completion of temperature gauges embedding. The regularity reflected by different dam sections is basically the same, and the typical temperature process line is shown in the figure 5.

Figure 5. The typical temperature process line.

1) At the early stage of burial (2008 ~2009), the temperature of each measuring point rose rapidly under the influence of the temperature rise of concrete hydration heat, and then the temperature gradually decreased. The temperature of the measuring point in the mud at the bottom of the reservoir has been decreasing slowly for a long time. In the spring and summer non-glacial period, the reservoir water temperature increases with the increase of the ambient temperature and decreases with the decrease of the ambient temperature. In the glacial period of the reservoir area every year, the ice plays the role of a temperature insulating layer. The temperature of the reservoir no longer changes with the change of temperature.

2) After water impounding in 2011, the change of water temperature is related to the fluctuation of environmental temperature, but there is an obvious lag, the water temperature at the bottom lags about half a year, and the water temperature near the surface lags about one month.

3) After the installation, the annual average temperature of the measuring point reached the highest value, and then the annual average water temperature basically decreased year by year.

4) When it is under the reservoir water level for a long time, the annual variation of water temperature is very small. With the increase of elevation, the annual variation gradually increases, and the correlation with temperature is more obvious.

4. Dam foundation temperature

Dam foundation temperature is one of the important boundary conditions that affect the temperature field of dam body, and mainly affected by water temperature, temperature and geothermal. In order to explore the change rule of foundation temperature, the 29# dam section was taken as a typical section for analysis. A group of temperature gauges were buried at 11.0m, 41.0m and 62.0m downstream of the dam axis in the 29# dam section (elevation of foundation surface is 626m, date of burial is May 11, 2007). The monitoring points of each group of temperature gauges were respectively located at 0m, 1m, 3m, 6m and 10m below the foundation surface. The graph is a typical foundation temperature timing process line.

Figure 6. The typical foundation temperature process line.
1) On the whole, there are three factors that affect the temperature of foundation: the ambient temperature, the heat generated by the dam concrete filling and the water seepage.

2) In the early stage of burial, the temperature of foundation at different depths is mainly affected by the ambient temperature, and the closer to the surface of foundation, the higher the temperature. From 2007 to 2008, under the influence of the heat generated by the hydration heat of concrete placing, the temperature of foundation increases, and the temperature decreases gradually after rising to the highest temperature.

3) Since the storage of the reservoir, the temperature of foundation is affected by the upstream reservoir water due to the periodic change of water temperature. The monitoring points at different parts of different dam sections are all periodic changes of temperature within the range of 10m below the foundation face, and at the depth of 10m below the foundation face have no obvious periodic changes.

4) The foundation has been in the process of continuous heat dissipation. After the temperature reaches the highest value, the temperature of foundation has a trend of slow decline, and the temperature of different dam sections at different elevations gradually tends to the same temperature (about 10℃).

5. Temperature of RCC dam body

Dam body temperature mainly includes downstream surface temperature, dam body temperature. The buried method of temperature gauges of downstream surface temperature of dam body is consistent with that of upstream. The temperature gauges of dam body is embedded in the interior of dam.

The dam body temperature in this section is analyzed by the temperature field[2]. Figure 7&8 is the variation law of temperature field of the dam body in severe cold season (January) and high temperature season (August) in the typical dam section 29# in different typical years.

1) Overall, the dam body internal temperature is the highest, the temperature is low in the dam toe, dam heel and dam crest.

2) The same dam section of the same year of summer and winter comparison: the dam body internal temperature change range is small, the upper and lower dam body surface is affected by the environment temperature greater (and the downstream surface is affected by sunshine, the change is greater than the upstream surface). The surface temperature is high in summer and low in winter. The temperature of dam toe, dam heel and base is lower in summer than in winter, which is consistent with the above analysis.

3) By comparing the dam body temperature over the years, it can be seen that the dam body is still in the internal heat exchange, has not reached a stable equilibrium system. The dam body temperature is in the process of adjusting to the stable field.

Figure 7. Typical section temperature field in severe cold season (2010, 2012, 2015).
6. Conclusion

Through the analysis of the temperature monitoring data of a dam in the alpine region, the following conclusions can be drawn:

1) The dam temperature monitoring results objectively and comprehensively reflect the dam’s location, construction process and characteristics at different operating stages. The main factors affecting the dam temperature change are the concrete pouring hydration heat, water temperature, environmental temperature, in addition to the dam body insulation layer, ice layer, the overflow dam section water situation, etc.

2) The temperature of the reservoir water is in the spring and summer non-glacial period, and the variation law of the reservoir water temperature and the ambient temperature is consistent. In the glacial period of the reservoir area, the ice plays the role of a temperature insulating layer. The change of the extreme value of the reservoir water temperature has a certain lag with the change of the ambient temperature. The water temperature at the bottom of the reservoir is basically stable.

3) The foundation temperature reaches the maximum under the influence of the heat of hydration in the early stage of dam constructing. After impounding, the overall foundation temperature tends to decline slowly, and the fluctuation caused by the influence of water temperature and ambient temperature becomes smaller and smaller, and remains at about 10°C. The annual variation is small, and it is basically kept at the level of about 1°C.

4) The dam body temperature internal temperature is the highest, the main reason is that the mass RCC due to the slow release of hydration heat, the dam body temperature is in a downward trend. The dam body is always in the bottom of the water, the long-term exposure of the top of the lowest temperature. The surface temperature of the overflow dam section affected by water will be lower than other parts. By comparing the dam body temperature over the years, it can be seen that the heat exchange is still taking place inside the dam body, the stable equilibrium system has not yet been reached, and the dam body is in the process of adjusting to the stable field.

Acknowledgments

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