Arch dam temperature control curve adjustment and its impact

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Abstract. With the improvement of intelligent temperature control technology, the "three phases and nine stages" temperature control curve used in the casting of extra-high arch dams also needs to be adjusted according to project requirements. In Baihetan Hydropower Station, the design is 120 days to reach the arch sealing temperature, but in the actual construction sometimes need to shorten or extend the length of time through the water, resulting in the arch dam concrete stress changes, so that the arch dam temperature control anti-cracking increased the difficulty. In this paper, we designed 90 days and 150 days to reach the arch sealing temperature through simulation calculation, and compared it with the standard working conditions. The results found that: shortening or extending the arch sealing temperature by 30 days brings less stress changes to the arch dam concrete, and the arch dam as a whole is in a safe range, and the temperature control curve can be reasonably adjusted according to the actual needs of the project.

1. Introduction

In the process of arch dam construction, sometimes the length of time to open water needs to be adjusted due to the construction schedule, such as the need to advance from the designed 120 days to reach the arch sealing temperature to 80 days for the large beam part of the Wudongde hydropower station table hole. At the same time the cooling water supply needs to be adjusted according to the project demand. At the same time, in the construction site due to special weather and machine failure and other reasons, resulting in cooling water is difficult to reach the arch sealing temperature in 120 days according to the design requirements, the length of the water needs to be adjusted accordingly[1-4]. In the above cases, it is necessary to consider the impact of stress on the bulk concrete by changing the cooling water to make the concrete reach the arch sealing temperature for a longer or shorter period of time, and Whether this meets the safety needs of the project.

For the concrete cooling water, first in 1931 by the U.S. Bureau of Reclamation in the Owasi arch dam cooling water experiments, the experimental results in line with expectations. Subsequently, during the construction of Hoover Dam, cooling water pipes were buried throughout the dam for cooling water circulation, and at that time all iron pipes were used for cooling water circulation, which were laid in a serpentine shape. During the design, many factors were considered, such as the cooling water flow rate, the temperature difference between the cooling water and the concrete, the length of
the buried serpentine pipe, the spacing between the buried serpentine pipe and the cooling water flow rate. During construction, the temperature drop gradient is controlled by reducing the amount of cooling water in the serpentine cooling water pipe or increasing the cooling water temperature in order to control the temperature drop magnitude. At this time, due to the early adoption of cooling through-water technology, only one cooling was proposed, and most of the river water was used by conducting cooling through-water at a later stage to make the temperature of the dam concrete drop rapidly to the dam sealing arch temperature. China's first use of cooling water technology in large volume concrete was in the 1950s, when it was used in the Xianghongdian Arch Dam. According to the design of the dam body buried in the cold water pipe, water pipe material for iron pipe, with the help of river water for an artificial cooling; Subsequently, the scale of China's large volume concrete construction projects increased rapidly, only a post-cooling can not meet the needs of the project, so in the 1970s added an initial cooling [5], used to reduce the maximum temperature of concrete, cooling time is generally 14 to 20 days; until the 21st century, when the Xiaowan Arch Dam was constructed, a large number of temperature cracks were found in the dam, So the cooling pass water became three phase cooling; in the subsequent large volume concrete placement are used to cool down the concrete by three cooling phases. In Table 1 below, the concrete cooling process for a typical arch dam in recent years. With the improvement of science and technology, the material of cooling water pipe has changed from the original iron pipe to the present HDPE pipe, and the mode of water circulation has become more refined, from the whole manual operation to the present intelligent water circulation mode. Regarding the research of temperature control curve, academician Zhu Bofang proposed the simulation of "small temperature difference, early cooling, slow cooling" in combination with Xiaowan project, which is divided into "three phases and nine stages" to effectively reduce the temperature stress inside the bulk concrete; subsequently, Lin Peng et al. proposed an intelligent control cooling and watering system based on the "three phases and nine stages" temperature control curve[6-8], which can achieve fine control on the "three phases and nine stages" temperature control curve, effectively avoiding many defects of manual watering and improving the accuracy of cooling and watering. Liu Jun et al. proposed a spatio-temporal dynamic control method for cooling water, which can further reduce the internal temperature stress of concrete by dynamically adjusting the time and temperature at the start of water circulation[9]; Zhao Zehu et al. optimized the temperature control curve of concrete by using the average degree of stress difference as the index, and concluded that the concave curve is the most effective in optimizing the internal stresses in mass concrete and can increase the crack resistance of the dam[10-12].

Table 1. Typical arch dam cooling staging process.

| Project Name | Concrete Cooling Staging                     |
|--------------|---------------------------------------------|
| Ertan        | One-phase cooling, two-phase cooling         |
| Xiaowan      | One-phase cooling, two-phase cooling         |
| Jinping level 1 | One-phase cooling, mid-term cooling, two-phase cooling |
| Laxiwa       | One-phase cooling, mid-term cooling, two-phase cooling |
| Xiluodu      | One-phase cooling, mid-term cooling, two-phase cooling |
| Dagangshan   | One-phase cooling, mid-term cooling, two-phase cooling |

2. Computational models and related principles

2.1 Computational Models
In this paper, the model used in the calculation process is the model of three dam sections in the riverbed of Baihetan arch dam, and the model is shown in Figure 1. The whole model contains 25622 units and 32074 nodes. At the same time, the concrete zoning provided by the design institute was taken into account in the calculation. The concrete in the three dam sections of the riverbed is Zone A from the base to 585 m elevation, Zone B from 585 m elevation to 680 m elevation, and Zone C from 680 m elevation to 834 m elevation.
2.2 Boundary conditions and related parameters

In this paper, by using three dam sections model of the riverbed as an example, the effects of self-weight load and temperature load are mainly considered in the calculation process. The boundary conditions of the temperature and stress coupled fields of the dam are considered in the calculation process as shown in Figure 2. The water storage case (S1) is not considered in the calculation process, and only three boundary cases, S2, S3 and S4, are considered.

Among them, S2 for the dam surface convective exchange occurs, while taking into account the influence of solar radiation and the surrounding exchange occurs radiative heat exchange; S3 for the foundation ground foundation deep ground temperature changes, long-term changes are small, approximately constant, the base can be considered as a class boundary; S4 for the foundation sidewalls to take adiabatic boundary. The parameters of various materials in the dam site area are shown in Table 2 below.
2.3 Calculated working conditions
The calculation considered three working conditions, the design of the working conditions refer to the actual project of Baihetan, see Table 3. three design working conditions corresponding to the temperature control curve as shown in Figure 3. in the design, 90 days to reach the arch sealing temperature curve, mainly on the basis of the marked temperature control curve to shorten the temperature control time, 150 days to reach the arch sealing temperature, is to keep the temperature control time unchanged, in the process of three times to extend the cooling time.

Table 3. Thermodynamic parameters of various materials in the dam area.

| Name of working condition | Description of working conditions |
|---------------------------|-----------------------------------|
| GK1-1                     | 90 days to reach arch sealing temperature |
| GK1-2                     | 120 days to reach arch sealing temperature |
| GK1-3                     | 150 days to reach arch sealing temperature |

Figure 3. Three design temperature control curves.
0.099MPa; the maximum cross-river tensile stress, downstream tensile stress, vertical tensile stress and maximum principal stress for 120 days at arch sealing temperature are 0.084MPa, 0.126MPa, -0.018MPa and 0.127MPa; 0.107MPa; the maximum cross-river tensile stress, downstream tensile stress, vertical tensile stress and maximum principal stress for 150 days at arch sealing temperature are 0.107MPa, 0.01MPa, -0.017MPa and 0.112MPa.

From the figure, it can be seen that all the 3 temperature control curves are in the safe range, which is much lower than the 2.0 safety curve. Among the 3 curves, the temperature control curve with the smallest tensile stress is the one that reaches the arch sealing temperature in 90 days, and the largest is the one that reaches the arch sealing temperature in 120 days. Therefore, the simple extension of the length of the water through the degree of influence on the concrete tensile stress is small, the need for good control of the length of cooling and cooling rate, which can effectively reduce the concrete tensile stress. The construction site can choose the appropriate temperature control curve according to the actual construction needs. Only 90 days to reach the arch sealing temperature curve has certain requirements for the water ventilation equipment, the site construction in the temperature control stage is generally used to stop the water, and then after the temperature rises to a certain degree, the cycle of water. Because of the reduction of the temperature control time, so the need for a long period of time continuous water, water ventilation equipment is difficult to free up time for other dividing rooms of concrete cooling, it is necessary to have sufficient water ventilation equipment.

Figure 4. 90 days to reach arch sealing temperature.

Figure 5. 120 days to reach arch sealing temperature.
4. Conclusions

In this paper, we calculate the stress change of concrete at different time lengths to reach the arch sealing temperature through simulation, and consider the stress change of concrete in different directions to derive the stress effect brought by shortening and extending in the standard temperature control curve. According to the calculation results: in the standard temperature control curve to shorten or extend 30 days to reach the arch sealing temperature, the arch dam internal concrete stress change is small, far below the 2.0 safety curve, the arch dam as a whole in a safe range; simply extend the length of time through the water on the arch dam concrete tensile stress effect is small, need to control the cooling time and cooling rate, which is the key to reduce the internal concrete tensile stress.

According to the calculation results and combined with the actual construction of the site, the analysis of different temperature control curve in the implementation of the process of problems, while the arch dam under various circumstances to adjust the length of time through the water to make the corresponding analysis, can help to a greater extent to make the actual project guidance, effectively reduce and avoid the risk of cracking of the silo surface, increasing the safety performance of the dam.

Acknowledgements

The authors are grateful for the financial supports of National Natural Science Foundation of China (No. 51839007) and China Three Gorges Corporation Research Project (No. BHT/0809).

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