Research on the Effect of Under-Aged Concrete Arch Grouting for Ultra-High Arch Dam in Alpine-Cold Region

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Abstract. In order to study the concrete excessive early stress and cracking risk caused by early cooling rate after the arch grouting of the ultra-high arch dam in alpine-cold region, the effect of grouting water cooling and temperature compensation are analysed. The results show that the under-aged concrete arch grouting in the constrained area, especially the strong constrained area, cause a large tensile stress due to continuous cooling and there is a risk of cracking. In actual construction, the early concrete temperature drop rate should be strictly required. Sealing at different ages has a certain effect on the later stress process. The tensile stress is the smallest at the 90-day age, the largest at the 60-day age, and the middle-sized at the 120-day age.

1. Introduction
Arch dams have become a widely used form because of superior dam type, strong overload and seismic capacity. With the development of technology, arch dams have developed into hyperbolic high and thin. The temperature control measures and concrete pouring ability requirements are getting higher and higher[1].

A hydropower station is located in the Qinghai-Tibet Plateau, with relatively cold climate, large annual and daily temperature changes, strong solar radiation heat, frequent cold waves accompanied by strong winds, long construction period in winter, which detrimental to the temperature control and crack prevention of concrete. In addition, the dam is a double-curved thin arch dam with a high concrete strength grade, which is intended to adopt the construction method of concreting without longitudinal joint. The foundation constraint stress is large, and the temperature control problem is particularly prominent. Generally, the concrete age of the seal arch grouting area is at least 120 days. Due to the inconsistent pouring schedule and the tight construction period of the steep slope dam section, the concrete age of some dam blocks in the summer arch sealing grouting area may be less than 120 days.

There are two problems with under-aged concrete arch grouting: one is that the under-aged concrete has low strength, and in order to quickly cool the under-aged concrete, continuous water cooling measures will be used, which causes excessive tensile stress and bring about the risk of
cracking[2]; the second is the temperature compensation problem of the early age concrete arch grouting[3]. When the arch is closed for 60 days and 90 days, the adiabatic temperature rises of the concrete, the self-generated volume deformation, creep and other factors are routinely used as a reference for 120 days. However, the period is not the same, so the cracking risk and temperature compensation of concrete arch grouting with under-aged concrete are urgent problems to be studied.

2. Principle of finite element approximate analysis of water pipe cooling

In the case of thin-layer pouring, the heat in the concrete block can be dissipated through the layer, and the cooling water pipe can be cooled to reduce the temperature by burying the cooling water pipe[4].

It is supposed that the outer radius of the equivalent cylinder cooled by the water pipe is \( b \), and the inner radius is \( c \). Then the average temperature rise of the cooled concrete is

\[
\psi = T_\omega + X_1 (T_0 - T_\omega) - T_p
\]

(1)

In the formula: \( T_\omega \) is the water temperature at the inlet of the water pipe; \( X_1 \) is the coefficient, which can be found by the relevant literature; \( T_0 \) is the initial temperature of the concrete at the beginning of cooling.

Approximately, the adiabatic temperature rise of hydration heat in the calculation period can be considered in \( T_0 \). Water pipe cooling starts at the time of pouring, then:

\[
T_{01} = T_p + \Delta \theta_1
\]

(2)

In the formula: \( T_p \) is the placing temperature; \( \Delta \theta_1 \) is the adiabatic temperature rise in the first period. The average temperature rise of concrete at the end of the first period is:

\[
\psi_1 = T_\omega + X_1 (T_{01} - T_\omega) - T_p
\]

(3)

During the second period:

\[
T_{02} = \psi_1 + \Delta \theta_2
\]

(4)

The average temperature rise of concrete at the end of the second period is:

\[
\psi_2 = T_\omega + X_2 (T_{02} - T_\omega)
\]

(5)

By analogy for other time periods, the time \( i \) period is:

\[
\psi_i = T_\omega + X_i (T_{0i} - T_\omega)
\]

(6)

In the formula:

\[
T_{0i} = \phi_{i-1} + \Delta \theta_i
\]

(7)

\( \Delta \theta_i \) is the adiabatic temperature rise at time \( i \).

3. Numerical calculation model

Part of the dam section of the arch dam is selected as the research object, twice the dam height in the vertical direction as the foundation, and 1.5 times the dam height in the upstream and downstream directions as the foundation. The grid has a layer of 0.5m along the height and 8 layers in the thickness. The surface of the dam is dense and the middle is sparse. The grid size of the horizontal river is about 5m. The calculation model and grid are shown in Figure 1 and Figure 2.
For temperature compensation of under-age concrete grouting and sealing arch, the main research is the effect of sealing time on arch stress process, and the simplified model that can reflect the sealing process is selected. As shown in Figure 3, the concrete blocks of two adjacent dam sections are selected, and the height of an irrigation area is taken vertically. Considering the symmetry, each concrete block is taken half, and the lateral normal constraints. The transverse joint between the two concrete blocks is simulated with a non-thickness contact element.

4. Study on the cracking risk of continuous water-cooling

Aiming at the typical dam of under-aged arch grouting, the cracking risk of under-aged concrete is studied by comparing the stress of different ages with the allowable tensile stress. According to experience, the allowable tensile stress is divided by the maximum tensile stress calculated by simulation. As long as the ratio is greater than 1, it can be considered that the concrete at the age meets the strength requirements and will not crack.

As the length along the river is the largest, for early-age concrete, the stress along the river is most notable. The ratio of the allowable tensile stress to the early downstream stress are shown in Figure 4 and Figure 5. If the ratio is less than 1, it means that the early stress is greater than the allowable tensile stress. As shown in the figure, for the strongly constrained area, continuous water cooling of the early-stage seal arch grouting causes a large tensile stress, which results in cracking risk; for the weakly constrained area and unbound area, as long as the cover cooling and grouting cooling are carried out simultaneously, and a certain gradient is formed, which can reduce the temperature difference between the upper and lower layers and reduce the tensile stress of the closed arch grouting during cooling.
5. Research on temperature compensation of grouting seal arch

As the concrete placing temperature is 12 degrees, under the influence of hydration heat and first-stage water cooling, the maximum temperature is close to 25 degrees, so the temperature rise is 13 degrees. Afterwards, it is continuously cooled by the first-stage water cooling and concrete covering water cooling. The arch temperature is about 7 degrees, and the temperature drop is 18 degrees in 40 days. At this time, the maximum tensile stress reaches 1.7 MPa, which reaches the allowable tensile stress value. In the first winter after all the joints being grouted, the surface stress exceeded the standard during the winter due to the influence of the summer arch and the dam located in the foundation restraint area.

The conventional stress control standards for arch dams are all based on the 120-days reference system. When the arches are sealed for 60-days and 90-days, the adiabatic temperature rise, volumetric deformation, creep and other factors are different with the 120-days. Therefore, the temperature compensation of 60-days and 90-days sealed arch grouting should be studied with the goal of stresses equivalence.

When the temperature of the concrete is stabilized to a stable temperature, the arch stress is greatest in 60-days, followed by 120-days, and the smallest in 90-days. Therefore, considering the temperature compensation based on the principle of stress equivalence, the closed arch should be altra cold in 60-days and undercooled in 90-days. By adjusting the arching temperature calculation, if the stress is equal when the temperature is stable, then the temperature at this time is the arching temperature considering temperature compensation.
Figure 6. Temperature history curves by considering temperature compensation.

Figure 7. Stress history curves considering by temperature compensation.

The temperature and stress processes after considering temperature compensation are shown in Figure 6 and Figure 7, in which the arch temperature at 60-days is 7.25 degrees, and the arch temperature at 90-days is 7.9 degrees. Compared with the 7.5-degree arching temperature at 120-days, the arching temperature at 60-days is reduced by 0.25 degrees, and the arching temperature at 90-days increased by 0.4 degrees.

6. Conclusion
Summer grouting is applied to the under-aged concrete in the base restraint area, then the stress during the later winter and early stress both exceed or reach the allowable tensile stress value. After leaving the base restraint area, if the surface high stress caused by the summer arch is not considered, due to the constraints weak, the tensile stress generated by continuous water cooling is less than the allowable tensile stress. Then the temperature drop rate of early concrete should be strictly required under construction.

Sealing at different ages have a certain effect on the later stress process. The tensile stress is the smallest at the 90-day age, the largest at the 60-day age, and the middle-sized at the 120-day age.

Different ages of arch sealing have certain influence on the later stress, by considering the stress equivalent when the concrete temperature at the later stage of arch sealing at different ages is reduced to the stable temperature, the temperature at 60 days is 0.1-0.25 degrees lower than the design temperature at 120 days, and the temperature at 90 days is 0.4-0.5 degrees higher than the design temperature.
Acknowledgments
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