Research on concrete temperature control measures in deep hole area of super high arch dam

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Abstract. The deep hole area is a key part of the dam during the construction period, and its temperature field and stress field changes are the focus of the current research on temperature control and crack prevention in the deep hole area. Based on the traditional three-stage and nine-stage temperature control standard, this paper uses three-dimensional finite element temperature stress simulation analysis to study the three major research ideas of shortening the medium-term cooling, shortening the second-stage cooling, and shortening the two at the same time. The concrete silo with a relatively lagging temperature control phase reaches the arching temperature at the same time. The simulation results show that the three temperature control measures can not only keep the stress in the area within a safe range, but also effectively shorten the construction period, providing new ideas for temperature control measures in the deep hole area of the arch dam.

1. Introduction
The temperature load is one of the main loads of the arch dam, which generally occupies more than 30% of the arch dam load, and the arch closure temperature directly affects the size of the temperature load[1]. The temperature load specified in the arch dam specification is divided into two types: temperature drop and temperature rise. They are the lowest and highest temperature during the operation period of the dam according to the boundary conditions of the dam site weather and reservoir water temperature, and then minus the arch closure temperature. The arch closure temperature is the starting point for the calculation of the temperature load of the arch dam. If the arch sealing temperature is reached too late, the deep hole area of the arch dam will reach a relatively unstable temperature field[2]. Arch dams are usually in a three-dimensional stress state due to their high stress level and complex stress conditions, while deep holes generally have openings in the middle and lower elevations of the dam body in high stress areas[3]. The openings in the arch dam have little effect on the overall working behavior and stress of the dam, but obvious stress concentration will occur near the openings. And large tensile stresses will appear in local parts around the openings[4]. This leads to local cracks in the concrete. Special attention should be paid to the temperature control measures in the deep hole area of the arch dam.

The concrete materials around the orifice are more complex. The corbel area downstream of the orifice is poured with high-heating and high-strength materials such as secondary or self-compacting concrete. The highest temperature in the area is not easy to control, in addition, the concrete pouring
season is generally in the high temperature season or the autumn sub-low temperature season, which is not conducive to temperature control and crack prevention[5]. Therefore, in comparison, the selection of materials in the orifice area to the pouring, temperature control, curing, and subsequent water storage in the concrete construction process may have an important impact on the concrete cracking in this area. Once any link is not in place, it is easy to cause concrete cracking at the orifice. This article takes a double-curvature arch dam in the southwest as the background, and aims at the relative lagging of the temperature control stage of the concrete silo of the deep-hole dam section, causing the overall arch closure time of the irrigation area to lag 20 to 30 days. Based on the original three-stage and nine-stage standard temperature control time in the above, the idea of shortening the medium-term cooling, shortening the second-phase cooling and shortening both at the same time, using the three-dimensional simulation [10] method to carry out research, in order to make all the concrete warehouses in the irrigation area reach the arch sealing temperature simultaneously, thereby effectively shortening the arch sealing of the irrigation area Grouting cycle.

2. Analysis of dam performance

2.1. Project Overview
A high dam in the southwest is located in Ningnan County of Sichuan Province and Qiaojia County of Yunnan Province on the lower reaches of the Jinsha River. After completion, it will mainly generate electricity, take flood control into account, and greatly improve downstream navigation conditions and sand retention. The crest elevation of the concrete arch dam is 834 meters, the dam height is 289 meters, the maximum arch end thickness is 83.91 meters, the dam crest thickness is 14 meters, including the expanded foundation, the maximum thickness is 95 meters, and the dam crest arc length is about 709.0 meters. There are 31 in total Dam section, 30 transverse joints. The entire dam body contains 6 surface holes, 7 deep holes, and 6 bottom diversion holes, which are arranged in the 15#~22# dam section in the center of the arch dam. With the continuous pouring of the dam concrete, the deep hole area concrete pouring will be basically completed in February 2020.

2.2. Calculation model
This study mainly uses a representative riverbed dam section refined model, which includes detailed structures such as bottom holes, deep holes, and surface holes, and refines the local meshes of the deep holes that are focused on to improve calculations. Accuracy, the whole model has 149041 units and 170399 nodes.

![Figure 1. Refined model of riverbed dam section.](image)

2.3. Boundary conditions and related parameter settings
As the upstream boundary concrete mainly exchanges heat with the surrounding medium air, according to the four types of boundary conditions summarized by Academician Zhu Bofang, the third type of boundary conditions is taken as the simulation boundary condition, and the foundation is approximately an adiabatic boundary[6]. The simulation analysis mainly considers the self-weight load and temperature load of the dam body, and considers the change of concrete elastic modulus with age and the creep effect
of concrete. The temperature load includes the temperature rise of the hydration heat of the concrete during the construction period, the cooling effect of water pipes, the influence of the external temperature, and the surface insulation measures. The external temperature data adopts the actual on-site monitoring as the temperature boundary condition.

| Materials | Bedrock | DamC30 | DamC35 | DamC40 |
|-----------|---------|--------|--------|--------|
| Modulus of Elasticity /GPa | 26 | 40.7 | 41.7 | 44.6 |
| Poisson's ratio | 0.25 | 0.211 | 0.223 | 0.215 |
| Coefficient of linear expansion $\alpha$/(10^{-6}/°C) | 6.79 | 6.5 | 6.5 | 6.5 |
| Weight capacity / (kg/m³) | 2500 | 2421 | 2423 | 2422 |
| Specific heat capacity / [kJ/(kg°C)] | 0.85 | 1.07 | 1.04 | 1.01 |
| Adiabatic temperature rise $\theta_{a}$/°(C) | None | 21.1 | 23.5 | 24.9 |
| Exothermic coefficient of heat of hydrationm | None | 0.252 | 0.252 | 0.252 |
| Thermal conductivity / [kJ/(md°C)] | 185.04 | 160.56 | 159.84 | 164.16 |

2.4. Calculation conditions

Based on the traditional three phases and nine stages, this paper studies and calculates 10 different working conditions. Under the premise of meeting the temperature control standards, advance the number of medium-term cooling days by 10 days, 15 days, and 20 days, respectively, advance the number of cooling days in the second phase by 10 days, 15 days, and advance both the mid-term and second-phase cooling by 15 days, simulation analysis in 20 days, 25 days and 30 days.

| Name of working condition | Cooling stage | Mid-term cooling | Second stage cooling | Description |
|---------------------------|---------------|------------------|----------------------|-------------|
|                           |               | Temperature control once | Intermediate cooling | Secondary temperature control | Secondary cooling | |
| GK0                       | Temperature control standard (days) | 20 | 30 | 20 | 30 | Control condition |
| GK1-1                     | -5            | -5               | -5                   | Shortened by 10 days |
| GK1-2                     | -5            | -5               | -10                  | Shortened by 15 days |
| GK1-3                     | -5            | -5               | -10                  | Shortened by 20 days |
| GK2-1                     | Shorten the second cooling | -5 | -5 | -10 | -10 | Shortened by 10 days |
| GK2-2 | -15 | | | | |
| GK3-1 | Simultaneously shorten the intercooling and secondary cooling | -5 | -5 | -5 | -5 | Shortened by 15 days |
| GK3-2 | -10 | | | | |
| GK3-3 | Shorten the second cooling | -5 | -5 | -5 | -10 | Shortened by 20 days |
| GK3-4 | -10 | | | | |

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3. Simulation result analysis

3.1. Shorten mid-term cooling
According to the traditional three-stage and nine-stage temperature control measures, a high dam in Southwest China will control the number of medium-term cooling days to about 70 days, which are the primary temperature control in the medium term, the secondary cooling temperature in the medium term, and the secondary temperature control in the medium term. Mid-term cooling is a continuous water cooling between the first-stage cooling and the second-stage cooling, which can not only better control the temperature rise, but also reduce the cooling amplitude time between the first-stage cooling and the second-stage cooling[7]. The first-stage cooling and mid-stage cooling are carried out continuously to better control the temperature gradient. If only the first-stage cooling and the second-stage cooling are adopted, after the first-stage cooling is completed, the temperature of the concrete will rise due to the influence of the heat of hydration in the later stage. In particular, the high-mixed fly ash concrete has greater heat release in the later stage and the temperature rise is more obvious. The early stage of the Xiaowan arch dam established in my country did not set mid-term cooling for the second stage cooling, and the second-stage cooling rate reached an effective 20%[8]. Degree resulting in penetrating cracks; In the later stage, after a series of temperature control measures were adjusted, the three-phase cooling method was adopted, and the temperature rise after the first-phase cooling was well controlled, effectively controlling the development of cracks. Zhang Guoxin and others pointed out that when there is no mid-term cooling stress, the temperature stress appears as a tensile stress of 2.2 MPa, and the safety factor is only 1.38; after increasing the mid-term cooling, the maximum tensile stress is reduced by 0.4 to 0.8 MPa, and the safety factor meets the requirements[9]. This paper selects the 16-dam section 65 bins that most affect the arch sealing requirements of the 22nd irrigation area as the main body of the research. When the concrete bins of other dam sections in the 22nd irrigation area have entered the mid-term cooling, the 16-dam section 65 bins are still in the first phase of cooling. Therefore, this section focuses on the temperature and stress changes in the warehouse under the condition of shortening the cooling days in different mid-terms. The results show that the early mid-term cooling of the 65 bins in the 16 dam section will lead to a certain increase in the stress level during the cooling period. The mid-term cooling 20 days early stress is about 0.07 MPa and 0.19 MPa higher than the mid-term cooling 15 days and 10 days earlier, and all are within the safe range.

3.2. Shorten the second stage cooling
The second-stage cooling time is the connection of the water cooling before the dam joint grouting and the mid-term cooling time. The dam body is reduced to the target temperature before the joint grouting. A high dam in the southwest will control the second-stage cooling to 30 days. In this paper, based on the basic temperature control measures, the second-phase cooling is shortened by 10 days and the
relevant concrete at the deep hole position of 15 angels meets the arch sealing requirements together with the irrigation area[10]. As shown in the figure, the 10-day and 15-day reduction of the second-phase cooling has little effect on the stress and temperature of the 16#65 warehouse, which are all within the safety margin.

Figure4. Second-phase cooling advance temperature time history line.  
Figure5. Second-phase cooling advance stress time history line.

3.3. Both shorten
The purpose of the mid-term cooling and the second-phase cooling is actually to reduce the temperature difference in time and space. The temperature difference in time refers to the temperature difference corresponding to the adjacent moments of the same part, and the temperature difference in space generally refers to the upper and lower layers. The difference between the temperature changes of the adjacent dam sections before and after, if the temperature difference between the two adjacent dam sections is not well controlled, temperature stress will be generated, which is not good for arch dam crack prevention. At the same time, shorten the cooling time of the two by 15 days, 20 days, 25 days and 30 days. According to the simulation results, shortening the second-phase cooling age at the same time will correspondingly increase the stress in the middle of the 16#065 warehouse, and shorten the 30-day stress ratio at the same time. The stresses of 15 days, 20 days, and 25 days are respectively greater than 0.23 MPa, 0.11 MPa, and 0.12 MPa, but they are all within the safety margin. According to the above simulation results, if the 15-day cooling is shortened, the maximum stress in the medium-term cooling is 4 to 5 days earlier than the two simultaneous shortening and the second-stage cooling is shortened, and the stress is reduced by about 0.06 MPa and 0.63 MPa, respectively. When the two are shortened by 30 days at the same time, although the stress is relatively large compared with other working conditions, it is still within the safety margin.

Figure6. At the same time advance the temperature process line.  
Figure7. At the same time advance the stress process line.
4. Conclusions
Based on the standard temperature control measures, this paper studies three temperature control optimization measures, namely shortening the mid-term cooling, shortening the second-phase cooling, and shortening at the same time. Several temperature control measures make the concrete silo that is relatively lagging in the temperature control stage of the irrigation area reach the arching condition at the same time as other concrete silos in the irrigation area, and all are within the safety margin. The three temperature control optimization measures can not only ensure that the temperature stress is within a relatively safe range, but also greatly shorten the construction period, save costs, and provide certain help for the temperature control measures in the later arch dam construction.

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