Stress Analysis of Extra-high Arch Dam with Closed Arch Grouting during Summer Constructions

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Abstract. In this paper, the stress state of the summer arch grouting area of the extra-high arch dam is studied to determine how the summer arch grouting will affect the dam body, considering the dead weight, water pressure, temperature and other loads. The results show that the most unfavourable working case after considering the dead weight and water pressure of the arch dam is that no water storage in the winter. The upstream arch direction should consider a certain amount of tensile stress superimposed by the dead weight and water pressure. The high stress of the surface concrete in the closed arch grouting area in summer may cause the strength of the transverse joint to reopen after grouting. After the transverse joint pulled apart, the arch stress in other parts is released.

1. Introduction
A hydropower project is located on the Qinghai-Tibet Plateau, with relatively cold climate, large annual and daily temperature changes, dry climate, strong solar radiation heat, frequent cold waves accompanied by strong winds, long construction period in winter, etc. Temperature control and crack prevention are disadvantageous. In addition, the dam is a double-curved thin arch dam with a large dam and a high concrete strength grade. The dam is intended to adopt the construction method of pouring without longitudinal joint. The foundation constraint stress is large, and the temperature control problem is particularly prominent[1].

When the dam joint grouting is constructed, the concrete temperature on both sides of the grouting area and the upper weighted concrete need to be cooled to the design temperature. In principle, the joint grouting construction cannot be carried out in summer[2]. However, due to the construction period, if the joint grouting adopts conventional technical standards, it is difficult to meet the dam construction schedule [3]. Therefore, the feasibility of prolonging the joint grouting period and optimizing the technical standards have very important engineering significance for the project schedule management and the timely realization of the impoundment[4].
2. Basic theory

Under the effect of temperature load, concrete not only produces elastic deformation, but also produces creep deformation with time. The creep deformation of concrete not only depends on its stress state and its duration, holding time, loading age, but also is affected by temperature and duration[5]. According to a large number of experimental studies, in addition to affecting the basic creep $C_{ctt}(t,\tau)$ of concrete, when the temperature is first raised to a certain value, transient creep $C_{ttc}(T,t,\tau)$ will occur. According to the principle of virtual work, it is not difficult to derive and calculate the temperature creep stress matrix equation of the element of the concrete structure under the action of heat and force:

$$
\{K_n\}^e \{\Delta \delta_n\}^e = \{\Delta P_{nc}^e\}^e + \{\Delta P_{hn}^e\}^e + \{\Delta P_T^e\}^e + \{\Delta P_o^e\}^e + \{\Delta F_n\}^e
$$

(1)

Where, $[K_n]$ is the element stiffness matrix:

$$
[K_n]^e = \int_{\Omega} [B]^T [D_n] [B] d\Omega
$$

(2)

$\{\Delta \delta_n\}^e$ is the incremental vector of element node displacement;

$\{\Delta P_{nc}^e\}^e$ is the equivalent load of transient creep;

$\{\Delta P_{hn}^e\}^e$ is the equivalent load of the n-period basic creep increment;

$\{\Delta P_T^e\}^e$ is the equivalent load of element temperature difference deformation increment.

$\{\Delta P_o^e\}^e$ is the n-period unit node force increment.

Collect all the elements, you can get the stress analysis matrix equation of the structure:

$$
[K_n]\{\Delta \delta_n\} = \{\Delta P_{nc}\} + \{\Delta P_{hn}\} + \{\Delta P_T\} + \{\Delta P_o\} + \{\Delta F_n\}
$$

(8)

After the calculation of $\{\Delta \delta_n\}$, the structural stress can be easily determined.
3. Numerical analysis model
Selecting a hydropower project as the research object, the main buildings of the hub include barrage dams, underground powerhouses on the right bank, water diversion and discharge structures, etc. The water-retaining building is a logarithmic spiral hyperbolic thin arch dam with a height of 250m and a bottom width of 49m. The calculation model uses twice the dam height in the vertical direction as the foundation, and 1.5 times the dam height in the upstream, downstream and left and right bank directions as the basis.

4. Analysis of the consequences caused by high stress in the closed arch grouting area in summer

4.1 Dam body stress under dead weight and water pressure
Arch dam pouring height is up to 190m and grouting height is up to 166.5m. In the winter of that year, the reservoir impounded water to 160m height. After impounding, the temperature drop in the upstream face of the arch grouting area in summer was reduced, and the surface stress was less than 1.5MPa. The dead weight hydraulic pressure load mainly considers the situation before the winter of that year.

Since the high stress brought by the summer arch closure is mainly the arch stress, this section mainly studies the arch stress under the action of dead weight and water pressure. Figure 2 is the arch stress envelope diagram of the calculated working case, where Figure 2 (a) and (b) are the upstream envelope diagrams of working case 1 and 2, (c) and (d) is the downstream envelope diagram of the working case 1 and 2. This article focuses on the area of 120m～150m of the dam.
It can be seen from the figure that for most of the areas away from the foundation surface, the upstream surface of case 1 (before water storage) has a tensile stress of 0.2~0.4MPa, and case 2 (after water storage) is compressive stress, where the minimum compressive stress of the downstream surface is -0.2MPa.

4.2 Dam body stress in the summer with closed arch grouting area of the riverbed dam section without considering dead weight

Usually, both the dead weight and the temperature load are considered in the calculation of the arch dam. In this paper, only the temperature load is applied to the dam body stress in the summer-sealed arch grouting area of the riverbed dam.

This paper studies the stress of the dam body stress in the summer with closed arch grouting area of the riverbed dam section only under the action of temperature load, and analyses whether the influence of concrete dead weight on the arch stress of the dam body is considered.

It can be seen from the figure 3 that the dead weight has little influence on the arch stress of the dam body in the summer arch grouting area.
4.3 Analysis of the consequences of high stress in the closed arch grouting area in summer

After comprehensive consideration of water pressure, dead weight, temperature load and many other factors, the high surface stress in the closed arch grouting area in summer will have different effects in different parts.

Under the effect of dead weight and water pressure, the arch surface tensile stress of 0.2~0.4MPa is generated before the initial storage of the upstream surface, which is not conducive to the crack resistance of the surface. The tensile stress near the foundation surface of 120-150m elevation is less than 0.2MPa. Under the effect of dead weight and water pressure, the downstream surface of 120-150m elevation is all compressive stress, and with the increase of water storage height, compressive stress increases. Therefore, storing water in winter according to the existing schedule can reduce the tensile stress and reduce the risk of cracking.

The most unfavorable working case is that there is no water storage in winter, the upstream surface arch direction should consider the 0.2~0.4MPa tensile stress superimposed amount brought by the dead weight and water pressure. The distribution of the maximum tensile stress along the dam thickness after superposition is shown in Figure 4.

![Figure 4. Distribution of the maximum tensile stress along the dam thickness after the effect of superimposed dead weight and water pressure (not stored in winter in that year)](image)

In general, the strength of the transverse joint after grouting is lower than that of ordinary concrete. Therefore, the high stress of the surface concrete in the closed arch grouting area in summer may cause the strength of the transverse joint to reopen after grouting. According to the stress diagram in Figure 4, it can be judged the depth of the horizontal seam is 2~4m. If the strength of the transverse joint is higher than the strength of the concrete on the dam face, to allow the tensile stress to be controlled by 2.08MPa, vertical cracks will appear on the dam face, with a crack depth of 0.5m~1m.

4.4 Variation of stress of dam body caused by the opening of transverse joint after grouting

Generally speaking, the tensile strength after transverse grouting is generally less than that of ordinary concrete. Due to lack of test data, this article preliminarily proposes that the transverse joint strength after grouting is 1MPa. In this way, the high surface stress will first cause the transverse seam to reopen after grouting. The depth of the transverse seam depends on the range of the tensile stress exceeding the standard. This section studies the stress changes in other parts of the dam body after the transverse joint is reopened. After the grouting, the horizontal joint is reopened, and the surrounding concrete arch stress is released. Figure 5 is a comparison of the maximum principal stress process line of the middle dam section at 149.5m elevation along the horizontal river to the midpoint of the two working cases.
Figure 5. Comparison of the process lines of the maximum principal stress of the middle downstream face point of the middle dam section after the opening of the Joint

It can be seen from the Figure 5 that after the transverse joint is pulled apart, the arch stress of the surrounding concrete is released, and the maximum tensile stress in the middle of the dam is reduced from 2.1MPa to 1.3MPa, which is less than the allowable tensile stress.

5. Conclusion
After considering the dead weight and water pressure of the arch dam, the most unfavorable working cases that no water storage in those winter, the upstream arch direction should consider the superimposed amount of 0.2~0.4MPa tensile stress brought by the dead weight and water pressure. After the grouting, the strength of the transverse joint is lower than that of the ordinary concrete. The high stress of the surface concrete in the closed arch grouting area in summer may cause the transverse joint to be reopened after grouting, then the stress in other parts is released. If the strength of the transverse joint is higher than the strength of the concrete on the dam face, to allow the tensile stress to be controlled by 2.08MPa, vertical cracks will appear on the dam face, with a crack depth of 0.5m~1m.

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