

Study on Optimization of Temperature Control Measures for Structure Concrete of Arc Dam

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Abstract. As the gate pier bracket of an arch dam are of complex structure which is characterized by use of high-grade concrete and more cement, higher adiabatic temperature rise, it is rather difficult to control temperature and vulnerable for cracking, and the cracks would absolutely affect the integrity, endurance and safety of pier gate bracket. It is necessary to take reasonable temperature control measures to reduce temperature stress during the construction and prevent cracking. This paper takes the gate pier bracket at the middle-hole dam section to perform simulation analysis of temperature field and stress field under different temperature control measures by 3D FEM. It proves that such measures as densifying water pipes, improving Phase I target cooling temperature appropriately, reducing Phase I cooling temperature falling variation and keeping insulation in low-temperature season can help reduce temperature stress and prevent cracking with good results.

Keywords. Gate pier bracket, simulation computation, temperature control to prevent cracking, water cooling

1. Introduction

For a concrete dam which is designed to have the function of discharging flood, tainter gate is usually used at the gate opening at both sides of which are arc-gate support structure including pier gate bracket with long cantilevers and girders. As these parts are of complex structure which is characterized by use of high-grade concrete and more cement, higher adiabatic temperature rise, it is rather difficult to control temperature and vulnerable for cracking, and the cracks would absolutely affect the integrity,

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endurance and safety of pier gate bracket. It is necessary to take reasonable temperature control measures [1] to reduce temperature stress during the construction and prevent cracking. Taking the gate pier bracket at the middle-opening dam section of a dam project, this Paper performs simulation computation to compare and analyze temperature control measures and conduct reasonable optimization of the temperature control measures at the pier gate bracket.

2. Research Approach

The said dam project is located in the west of Sichuan Province where it is of plateau climate, and the dam site has relatively low temperature on average and complex climate condition, with big range of extreme temperature difference between daytime and nighttime. Therefore, the temperature control at the pier gate bracket is rather difficult, especially the control of maximum temperature and the temperature falling rate. It is necessary to conduct research on temperature control and propose reasonable and effective temperature control measures. By using finite element simulation analysis of the whole-dam construction process [2], this Paper simulates the concrete placement, water retaining, concrete heating and curing, creeping, water cooling and insulation ranging from pouring commencement to water retaining, as well as boundary conditions [3-4] such as meteorologic conditions, to analyze the the effects of different measures to control maximum temperature and the impacts of different temperature falling process on concrete stress and safety coefficient, before giving suggestions on optimizing the concrete temperature control measures at the pier gate bracket [5-6].

3. Research on 3D Finite Elements Simulation-based Temperature Control Optimization

3.1. Concrete Structure and Thermodynamic Parameters

See figure 1 for the section of pier gate bracket and material zoning. The level-2 aggregate grading concrete C35W10F200 and C30W10F200 and level-3 aggregate grading concrete C30W10F200 were used at the pier gate bracket. See table 1 and table 2 respectively for the thermodynamic parameters and tensile strength of the concrete at the pier gate bracket.

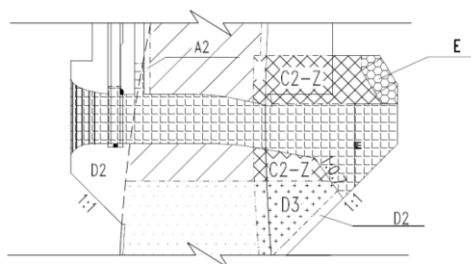


Figure 1. Section of pier gate bracket and material zoning.

Table 1. Concrete thermodynamic parameters at pier gate bracket.

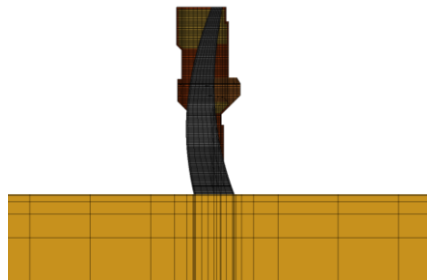
Strength grade	Thermal conductivity (KJ/m•h•°C)	Specific heat (KJ/kg•°C)	Coefficient of linear expansivity ($\times 10^{-6}/^{\circ}\text{C}$)	Adiabatic temperature rise ($^{\circ}\text{C}$)	Elasticity modulus	
					7d	28d
C35W10F200 (Level-2 aggregate grading)	8.51	0.92	10	$T=50.25/(1+2.4573/t)$	32.6	35.7
C30W10F200 (Level-2 aggregate grading)	8.43	0.94	10	$T=46.73/(1+2.4626/t)$	26.9	32.3
C30W10F200 (Level-3 aggregate grading)	8.43	0.94	11	$T=44.73/(1+2.4626/t)$	28.3	34.5

Table 2. Concrete tensile strength at pier gate bracket.

Strength grade	Axial tensile strength (MPa)	
	7d	28d
C35W10F200 (Level-2 aggregate grading)	2.48	3.09
C30W10F200 (Level-2 aggregate grading)	2.17	2.84
C30W10F200 (Level-3 aggregate grading)	2.24	2.96

3.2. Computation Model and Boundary Conditions

3D finite element computation grid model is shown in figure 2 below. The dam section consists of 6 material zoning. Considering the middle-opening dam section at the pier gate bracket, the grid is subdivided in spatial hexahedron and pentahedron isoparametric elements, a total of 67052 units and 79029 nodes, with solution degree of freedom approaching 240,000. When calculating temperature field, the surrounding and bottom of the bedrock are both adiabatic boundaries, with the foundation size not less than 1.5 times the dam height; the dam lateral surfaces are adiabatic boundaries, with other surfaces being heat exchange boundary, and the ambient temperature is perennial mean temperature. The left and right sides of the bedrock are normal constraints, with the bottom being fixed constraints.

**Figure 2.** Simulation computation model of middle-opening dam section.

3.3. Working Conditions

By adjusting water-cooling pipe spacing and Stage-1 cooling target temperature, we analyze the temperature and stress under different working conditions [7]. When computing, we take into account self-weight load, temperature load, concrete autogenous volume deformation and creeping. See table 3 for the specific working conditions.

No.1 working condition: Water pipe spacing is 1.0m*1.0m, with the target temperature at Stage-1 cooling being 22°C, 17°C at intermediate cooling and 12°C at Stage 2 cooling.

No.2 working condition: Densify water pipes to make water pipe spacing 1.0m*0.8m, with the remaining temperature control measures same as No.1 working condition.

No.3 working condition: Densify water pipes to make water pipe spacing 1.0m*0.8m, and the cooling target temperature is raised from 22°C to 25°C, with the remaining measures same as No.1 working condition.

Table 3. Working condition of concrete calculation at pier gate bracket.

Sr. No.	Water pipe spacing	Stage 1 cooling target temperature (°C)	Intermediate cooling target temperature (°C)	Stage 2 cooling target temperature (°C)
No.1 working condition	1.0m*1.0m	22	17	12
No.2 working condition	1.0m*0.8m	22	Same as No.1 working condition	Same as No.1 working condition
No.3 working condition	1.0m*0.8m	25	Same as No.1 working condition	Same as No.1 working condition

3.4. Analysis of Computation Results

The concrete used at the pier gate bracket is mainly poured with concrete of low grading and high slump, which features the intense hydro-thermal reaction, relatively higher adiabatic temperature rise and maximum temperature, as shown in figure 3. When the Stage 1 water cooling leads to the lower target temperature and the temperature drop is considerable, the maximum stress usually appears at the end of Stage 1 cooling period, although the previous elastic modulus of the concrete is low.

Under No.1 working condition, the water cooling pipes spacing is 1.0m*1.0m, the Stage 1 cooling target temperature is 22°C, the internal maximum stress of the concrete is 2.23MPa, as shown in figure 3 (b), with the maximum 34.6°C at the downstream pier gate bracket where C35 concrete is used, as shown in figure 3 (a); the maximum stress occurs at the end of Stage 1 cooling, with the relatively low safety coefficient of 1.29.

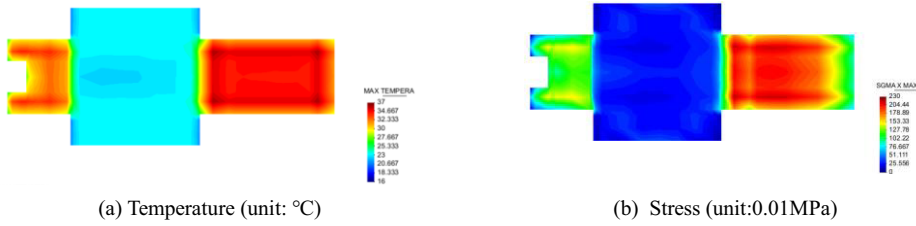


Figure 3. No.1 working condition - envelope diagram of stress of the middle section of pier gate bracket.

On the basis of No.1 working condition, the water cooling pipes spacing is densified to 1.0m*0.8m under No.2 working condition. Densifying the water cooling pipes can help lower the maximum temperature of concrete and reduce the temperature difference at Stage 1 cooling, thus reducing the stress at the end of Stage 1 cooling. After the water cooling pipes are densified, the internal maximum temperature is 32.9°C as shown in figure 4 (a), 1.7°C lower than that in No.1 working condition; the internal maximum stress is 1.64MPa, as shown in figure 4 (b), down by 0.59MPa from that in No.1 working condition; the safety coefficient rising from 1.29 to 1.75, plus the considerable improvement in the stress.

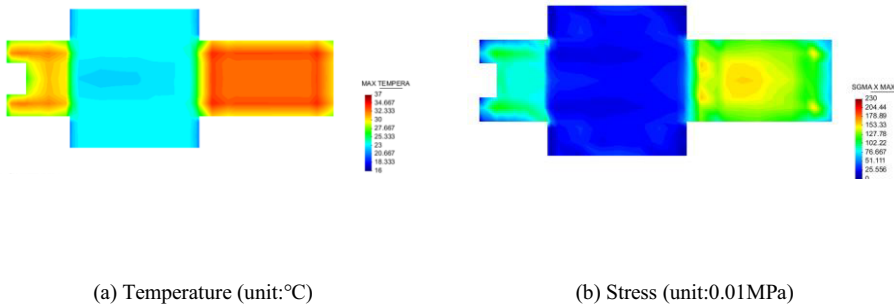


Figure 4. No.2 Working condition - envelope diagram of stress of the middle section of pier gate bracket.

Figure 5 (a) shows the temperature process curve. The results show that, on the basis of No.2 working condition, the target temperature at Stage 1 water cooling is raised from 22°C to 25°C under No.3 working condition. Raising the target temperature at Stage 1 water cooling has no impact on the maximum temperature. Since the target temperature at Stage 1 water cooling rises by 3°C, the cooling temperature difference is reduced. Raising the cooling target temperature can lead to the intermediate cooling temperature difference increasing and the stress increasing at the end of the intermediate cooling. But the simulated stress process curve is shown in figure 5 (b), and the results indicate that the maximum stress still appears at the end of Stage 1 cooling. Under this working condition, the internal maximum stress is 0.94MPa, as shown in figure 6, reducing by 0.7MPa from No.2 working condition, but the safety coefficient rises significantly to 3.08. This proves that raising the Stage 1 cooling target temperature at pier gate bracket can effectively reduce the internal stress.

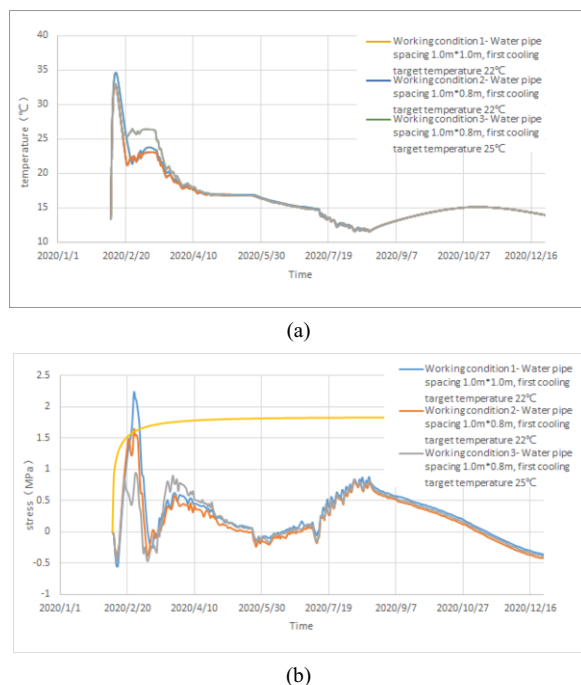


Figure 5. Temperature and stress process line at pier gate bracket under different temperature control measures.

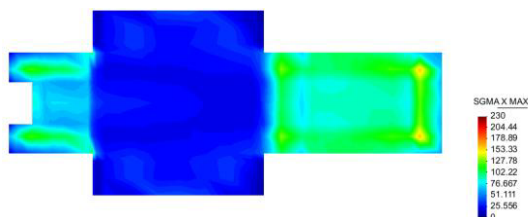


Figure 6. No. 3 working condition - envelope diagram of stress of the middle section of pier gate bracket.

4. Conclusions

Taking the middle-opening dam section of a dam project as example, this Paper conducts research on the temperature control at the pier gate bracket through simulation computation. The results show that (1) a large amount of high grade concrete is used at the gate pier bracket, hydro-thermal reaction is intense, with relatively higher maximum temperature. If the Stage I water cooling target temperature is lower, the cracking risks at the end of Stage I water cooling may be the greatest due to the large temperature drop. (2) Densifying water pipes help lower the maximum temperature of concrete and reduce temperature difference at Stage I water cooling. In particular, when the spacing between water-cooling pipes is changed from 1.0m*1.0m to 1.0m*0.8m, the maximum temperature falls by 1.7°C, with the internal maximum stress reducing by

0.59MPa. (3) Raising the target temperature at the Stage I water cooling appropriately can effectively reduce the temperature difference and the stress and at the Stage I water cooling. The target temperature at the Stage I water cooling can rise by 3°C while the internal maximum stress reduces by 0.7MPa. (4) Raising the target temperature at Stage I water cooling by distributing the temperature drop pressure to intermediate and final cooling, and the distribution of temperature drop must be distributed reasonably. The simulation analysis of whole-process temperature control can be conducted to develop solutions for temperature drop, minimizing the maximum cracking risk during the initial, intermediate and final cooling [8].

Acknowledgements

This project was supported by the following funds: National Key Research and Development Program of China, No.2018YFC0406703; National Natural Science Foundation of China, No.51779277; Special Research Project of Chinese Academy of Water Sciences (SS0145B712017, SS0145B612017, SS0145B392016); State Key Laboratory of Simulation and Regulation of River Basin Water Cycle, No.SK2020ZY10, NO.SS0112B102016; China Huaneng Group Science and Technology Project (HNKJ20-H21TB), Yalong River Technology Project

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