Concrete Temperature Control Measures for the Dagangshan High Arch Dam

Abstract

Since the 1990s, hydroelectric development in southwestern China has entered a period of rapid development, with arch dams becoming one of the preferred dam types for high dams due to their competitiveness. High concrete dams generate substantial hydration heat during the pouring process. Additionally, due to the large volume of the pouring blocks and uneven heat dissipation, significant temperature gradients and thermal stresses are produced during construction. Without proper control, these factors may lead to crack formation with serious consequences[1]. To prevent temperature cracks, a series of effective temperature control measures must be implemented during construction to prevent excessive temperature differentials in the concrete. This paper uses the Dagangshan high arch dam project under construction as an example to summarize the main temperature control measures and analyze their effectiveness. The conclusions drawn can provide reference for other similar engineering projects.

Keywords:

1. Project Overview

Dagangshan Hydropower Station is located in Shimian County in the middle reaches of the Dadu River, Sichuan Province. It is one of the large-scale hydropower projects on the main stream of the Dadu River. The controlled drainage area at the dam site reaches 62,700 km², accounting for 81% of the entire basin. The multi-year average flow rate is 1,010 m³/s. The normal reservoir water level of the power station is 1,130 m, with a total storage capacity of 777 million m³. The installed capacity of the power station is 2,600 MW. The hydraulic complex mainly consists of water retaining structures, flood discharge and energy dissipation structures, and water diversion and power generation structures. The water retaining structure adopts a double-curvature concrete arch dam with a maximum height of 210.00 m. The power generation diversion flow is 1,834 m³/s (4 × 458.5 m³/s), with a guaranteed output of 636 MW and an annual power generation of 11.43 billion kWh. The construction of Dagangshan Hydropower Station is of great significance for the comprehensive management of the Dadu River basin and the economic development of the entire region. As a focus of the entire engineering work, concrete temperature control of the dam is of great significance for ensuring the construction quality of the dam.

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The meteorological data for the dam site area uses statistical data from Shimian County Meteorological Station. The annual average temperature from 1961 to 1990 was 16.9°C, with the lowest monthly average temperature occurring in January at 8.0°C, and the highest monthly average temperature occurring in July at 24.5°C. The temperature statistics for Shimian County are shown in Table 1.

Table 1: Meteorological and Hydrological Data at Dagangshan Dam Site (Unit: °C)

Month	Average Air Temperature	Average Ground Temperature	Average Water Temperature
1	8.0	9.9	6.7
2	9.7	11.9	8.3
3	14.3	17	11.2
4	18.4	20.8	14.3
5	21.3	24.2	15.7
6	22.4	25.3	16.5
7	24.5	27.4	17.4
8	24.3	27.4	17.6
9	20.8	22.3	15.8
10	17.4	19.2	13.6
11	13.1	15.2	10.4
12	9.1	10.4	7.4
Annual	16.9	19.2	12.9

2. Water Cooling Measures

Water cooling is the most common and simplest effective measure to reduce the maximum temperature of concrete. However, during the water cooling process, excessive cooling rates can lead to significant temperature gradients near the cooling water pipes, resulting in microcracks that affect the load-bearing capacity of the structure. Therefore, in actual construction, it is necessary to strictly control the water temperature and flow rate, and make timely adjustments based on the current temperature state of the concrete.

During the construction of the Dagangshan arch dam, a "refined and personalized" water circulation principle was adopted. For concrete in different compartments with varying temperature states, the abnormal causes were promptly analyzed, and corresponding water circulation control plans were established, thereby gradually allowing the concrete temperature change process to develop according to the theoretical temperature process.

The cooling water pipes inside the dam body of the Dagangshan project are laid with HDPE plastic pipes, with a spacing of 1.0m~1.5m between the cooling water pipes, arranged in a serpentine pattern. The length of a single branch pipe does not exceed 300m. Based on the characteristics of temperature control and crack prevention in arch dam concrete, the water pipe cooling of the dam body is divided into three periods: primary cooling, intermediate cooling, and secondary cooling.

1. **Primary Cooling**

   The purpose of primary cooling temperature control is peak cutting, divided into temperature control and cooling stages. The total water circulation time for primary cooling is not less than 21 days, with a reference water temperature of 12°C~15°C. After controlling the maximum temperature, the difference between the cooling water and the internal concrete temperature is controlled within 15°C. The main task of the temperature control stage is to control the maximum concrete temperature not to exceed the allowable maximum temperature, with the allowable maximum temperature for concrete in the constrained area being 27°C and 30°C for the free area. The main task of the cooling stage is to control the cooling rate, with the maximum daily cooling rate being less than 0.5°C/day.

2. **Intermediate Cooling**

   The purpose of intermediate cooling is to prevent the temperature rise of concrete after the end of primary cooling. Through the slow cooling of intermediate cooling, the cooling amplitude of the secondary cooling of concrete is reduced. Intermediate cooling is divided into three stages: primary temperature control, cooling, and secondary temperature control. The main requirement of the primary temperature control stage is to maintain the concrete temperature stable at the target temperature of primary cooling, with a temperature variation amplitude of less than ±1°C. The main requirement of the cooling stage is to control the daily cooling rate to be less than 0.2°C/day. The main requirement of the secondary temperature control stage is to control the concrete temperature near the target temperature of intermediate cooling, with a variation amplitude of less than ±0.5°C.

3. **Secondary Cooling**

   The purpose of secondary cooling is to lower the concrete temperature to the arch closure temperature for joint grouting, divided into three stages: secondary cooling and cooling, temperature control, and grouting temperature control. The main requirement of the secondary cooling stage is to control the cooling rate to not exceed 0.3°C/day. The main requirement of the temperature control stage is to control the concrete variation amplitude to not exceed ±0.5°C. The main requirement of the grouting temperature control stage is to control the temperature variation amplitude to not exceed ±0.5°C, and for parts in the free area that need appropriate supercooling, the super-cooling amplitude should not exceed 2°C.

Figure 1 shows the temperature history curve of a certain dam section, where Tt1 and Tt2 are the measured temperature processes of two thermometers embedded in the concrete near the upstream and downstream sides. It can be seen that the temperature difference between the upstream and downstream of the compartment gradually increased from around May 26. The site promptly analyzed and identified the cause, finding that it was due to partial blockage of the cooling water pipes on the upstream side, leading to poor water circulation. Based on the "refined and personalized" water circulation principle, after analysis and demonstration, differentiated water circulation measures were adopted for the compartment, thereby gradually reducing the temperature difference within the concrete compartment.

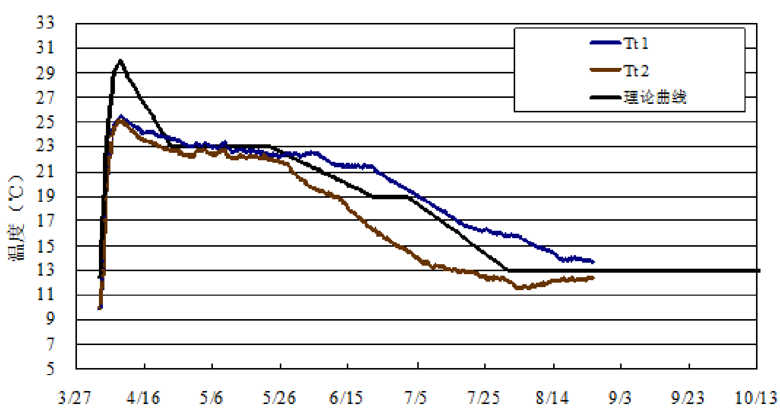

Figure 1: Temperature History Curve of a Certain Concrete Compartment

3. Insulation Measures

After concrete pouring, timely and effective insulation measures are typically required to prevent excessive temperature differentials between the interior and exterior that could lead to thermal cracking. The selection of insulation materials and thickness should be determined based on research of local climatic conditions.

Dagangshan is located in southwestern China, where temperature variations are significant. Therefore, permanent insulation is installed on both the upstream and downstream faces of the dam. Additionally, insulation blankets cover the compartment surfaces at night, and corridor entrances are sealed.

During high-temperature summer season pouring, excessively high ambient temperatures can easily cause the maximum concrete temperature to exceed the allowable maximum temperature. To address this, during concrete pouring, when the compartment air temperature exceeds 23°C, immediately after concrete vibration and compaction, the concrete surface should be covered with 5cm thick polyethylene roll material with a thermal conductivity coefficient ≤0.044W/m·°C for thermal insulation.

After completion of concrete pouring and compartment closure, when the compartment air temperature exceeds 20°C, the concrete surface should be covered with 5cm thick polyethylene roll material with a thermal conductivity coefficient ≤0.044W/m·°C for thermal insulation for 12 hours, with the maximum insulation time not exceeding 24 hours. Wet curing should be conducted after removing the insulation material.

In the event of sudden temperature drops, the concrete surface should be covered with 5cm thick polyethylene roll material with a thermal conductivity coefficient ≤0.044W/m·°C for insulation until the sudden temperature drop ends.

After removing the formwork from the arch dam transverse joints, 5cm thick polystyrene boards with a thermal conductivity coefficient ≤0.044W/m·°C should be immediately applied for insulation. After removing the formwork from the upstream face and completing the impervious protection treatment, 5cm thick polystyrene foam boards should be immediately adhered for year-round insulation until impoundment. After removing the formwork from the downstream face, 3cm thick polystyrene foam boards should be adhered within 5 days for year-round insulation, and generally should not be removed.

For special areas such as deep holes and diversion bottom holes in the dam body, 5cm thick polystyrene foam boards should be adhered to their top plates, bottom plates, side walls, and pier blocks within 5 days after formwork removal for year-round insulation.

4. Other Temperature Control Measures

For the same type of concrete material, the hydration reaction is basically consistent, thus the maximum concrete temperature has a certain relationship with the pouring temperature. To prevent the maximum concrete temperature from exceeding standards, it is necessary to strictly control the mixer outlet temperature, placement temperature, and ultimately ensure that the concrete pouring temperature does not exceed the allowable value.

To control the concrete mixer outlet temperature, it is required to pre-cool the concrete aggregates using primary and secondary air cooling measures, and adopt ice addition and refrigerated water mixing measures. To control the placement temperature, construction management must be strengthened to minimize transportation time, and concrete transport vehicles must be equipped with insulation, sun protection, and rain protection equipment. When the external temperature is excessively high, necessary water spraying cooling of the vehicle compartment exterior should be performed before loading.

To control concrete pouring temperature ≤12°C, high-temperature periods should be avoided for pouring, making full use of low-temperature seasons and early morning, evening, and night low-temperature periods for pouring. When the air temperature in the pouring compartment exceeds 23°C, mist spraying should be performed on the compartment surface to reduce the environmental temperature. Since excessively low pouring temperatures are unfavorable for concrete strength development, when the external daily average temperature drops below 4°C, the pouring temperature should not be lower than 7°C, and the pouring temperature of concrete poured in any season should not be lower than 5°C.

Additionally, using thin-layer concrete pouring for areas with strict temperature control requirements can improve concrete heat dissipation conditions, which is beneficial for controlling the maximum temperature and thereby ensuring engineering quality. The pouring layer thickness in this project generally adopts 3m, while the pouring layer thickness within the consolidation grouting overburden area of dam sections 6# to 25# is 1.5m. However, due to the thinner pouring layer, insufficient insulation during the cooling stage can easily lead to excessive cooling rates due to external influences. Therefore, special attention should be paid to the cooling process of the 1.5m thin-layer concrete.

5. Current Temperature Control Status of the Dam

During the concrete pouring process of the dam body, while adopting various temperature control measures, it is essential to constantly monitor the current temperature state of each compartment to guide the next step of on-site temperature control work.

During the dam body concrete pouring process of the Dagangshan project, the current temperature state of the dam is tracked in real-time, with special focus on controlling the maximum temperature of newly poured compartments and controlling the cooling rate of compartments in the cooling stage.

Figure 2 shows the current concrete age of each compartment in the dam. Figure 3 shows the current average concrete temperature of each compartment in the dam. Figure 4 shows the average maximum temperature of each compartment in the dam.

To achieve digital monitoring of the dam's temperature control status, a temperature control decision support system is used during construction to organize and analyze real-time temperature monitoring data, obtaining the current temperature state of the dam. Based on this, reasonable temperature control measures are proposed to guide on-site temperature control work.

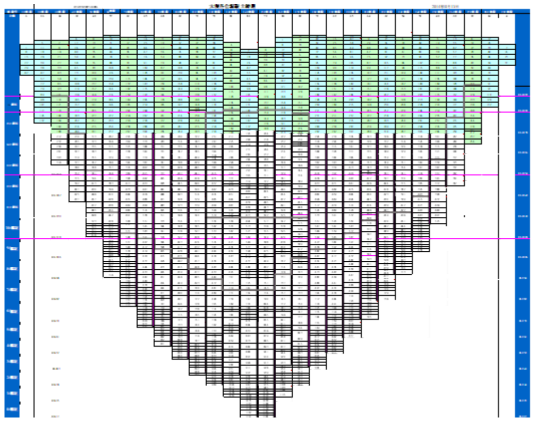

Figure 2: Current Concrete Age of Each Compartment in the Dam

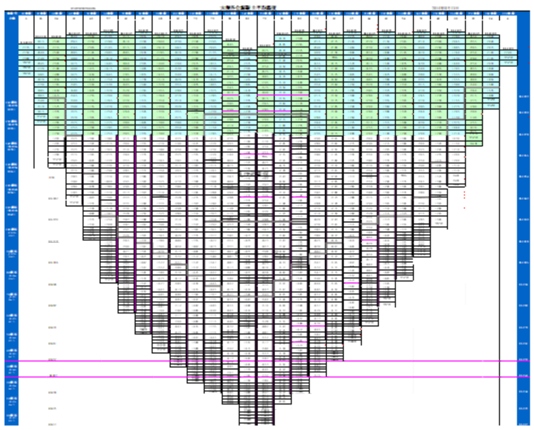

Figure 3: Current Average Concrete Temperature of Each compartment in the dam

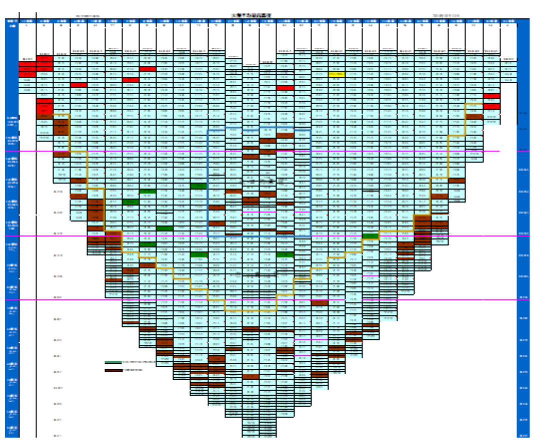

Figure 4: Average Maximum Temperature of Each Compartment in the Dam

6. Conclusions

This paper analyzes and summarizes the temperature control measures adopted in the Dagangshan project based on actual engineering practices. The main conclusions are as follows:

1. Practical engineering experience confirms that adopting "refined and personalized" water circulation schemes during the process of reducing concrete temperature through water cooling is beneficial for temperature control of abnormal compartments.
2. In southwestern regions with significant temperature variations, implementing timely and effective concrete insulation can reduce the risk of cracking due to excessive temperature differentials between the interior and exterior of the concrete.
3. When pouring concrete during high-temperature seasons, strict control of mixer outlet temperature, placement temperature, and pouring temperature helps control the maximum concrete temperature. Simultaneously, the pouring temperature during low-temperature seasons should not be excessively low to avoid hindering concrete strength development.
4. Utilizing intelligent and digital means to monitor the current temperature state of the dam and guide on-site concrete construction, implementing an effective operational mechanism of "field data - intelligent analysis - temperature control recommendations," is of significant importance for dam concrete temperature control work.

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