Design and implementation of a simulation optimization method for high arch dams

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Abstract. The construction scale of high arch dams is large and the overall structure is complex. Numerical simulation results obtained only by quoting standard parameters or laboratory measurements are quite different from actual engineering conditions. Based on a set of temperature-stress coupling simulation system, the key thermodynamic parameters used in the simulation calculation are further optimized through monitoring data and experimental results, so as to be close to the actual engineering state and better for studying the working status of high arch dams. Combined with actual applications, it is shown that the optimized results of the method are consistent with the actual objective laws, can better reflect the real situation, reduce the "noise" interference in the data, and verify the correctness and feasibility of the method.

1. Introduction

In recent years, the construction of "seamless" arch dams has become the goal of domestic high arch dam construction [1]. Due to the release of concrete hydration heat and poor heat dissipation characteristics of high arch dams during the construction phase, the temperature stress control during the construction process has always been the focus of attention and control. Many scholars have also carried out many studies in this direction. Scholars such as Zhu Bofang and Zhang Guoxin have proposed different calculation models of concrete hydration heat [2-3]; scholars such as Lin Nanxun and Zuo Zheng have proposed different concrete creep model [3-4]. However, the temperature problem of the concrete is a relatively complicated problem. In the past, the selection of temperature parameters was mostly obtained through experiments or empirical formulas, which generally had defects such as high cost and inconsistent with the on-site construction conditions.

Combining with the current status of my country's super-high arch dam construction and research status, the author believes that the current simulation calculation as an important support for structural safety during the construction of high arch dams requires the following two points:

- Regular update and processing of monitoring data. A large number of temperature and stress monitoring instruments are buried in each project. Especially in construction in Southwest China, a temporary thermometer is buried in the concrete of each warehouse, and thousands of CSV data are generated every hour during the construction process. On the one hand, it is necessary to call the monitoring data in time to serve as a reference for the construction; on the other hand, the amount of monitoring data is huge, and the uncertainty of construction causes a lot of “noise” in the monitoring.
data. The accuracy needs to be determined according to the actual construction requirements. Remove
the false and keep the truth, and extract the corresponding temperature stress development curve.

- Personalized setting of simulation parameters and dynamic correction of construction. Due to the
  complex structure of the super high arch dam and the different construction conditions, different
  engineering simulation parameters need to be personalized according to standards and practices, and the
  construction points of different stages need to be distinguished. According to the intelligent construction
  closed-loop system for dynamic correction of construction, at the same time, simulation verification,
  machine learning and other means can be used to review and modify the simulation parameters in time.
  Through the simulation results, it is possible to better understand the working status of the project
  construction process in order to discover and solve potential risks in time.

This article takes a super high arch dam project in Southwest China as an example, uses Douglas-
Peucker algorithm and cubic spline interpolation as the data processing method, reads and reduces the
noise of the monitoring data, and realizes the batch processing of the monitoring data through the
database and computer language programs. And according to the monitoring data, the simulation
parameters are reviewed and modified to realize the optimization of simulation calculation.

2. Project Overview

A hydroelectric power station in the southwest is composed of major buildings such as a barrage, flood
discharge and energy dissipation facilities, and a water diversion and power generation system. The
barrage is a concrete double-curved arch dam with a crest elevation of 834m, a maximum dam height
of 289m, a crest thickness of 14.0m, and a concrete volume of about 8.03 million m³. The use of low-
heat cement concrete for the entire dam is an attempt in my country to use low-heat cement concrete for
the entire dam of a super high arch dam.

The temperature monitoring of the arch dam is divided into permanent thermometers and temporary
thermometers. Permanent thermometers choose 4#, 9#, 15#, 18#, 21#, 26# dam sections as speci-
fical temperature monitoring sections, and one layer of thermometers is arranged every 15-20m height
difference. At the same time, the “three beams and six arches” section, which is the focus of stress and
strain monitoring, are supplemented with embedded thermometers to ensure that the temperature field
analysis can be performed at the stress and strain monitoring section at the same time. In addition, 1-2
internal thermometers are placed between the concrete cooling water pipes of each warehouse for
temporary thermometers. The monitoring data of thermometers and strain gauges will be summarized
weekly by the Engineering Data Monitoring Center. The analysis in this article uses the original
monitoring data obtained by the monitoring meter as the first-hand data to be processed, as a fitting
reference for the simulation calculation.

The monitoring data of the ultra-high arch dam used in this calculation is as of October 2020, with a
total of 20 million statistical monitoring data, and the total size of the monitoring data file in CSV format
is 1.2GB. Among them, due to the different number of thermometers in each bin, and the different time
intervals for generating data, the overall data has spatio-temporal disorder, and certain processing needs
to be performed before it is combined with simulation calculation.

3. Design of the simulation optimization method

3.1. Monitoring data processing
To review the finite element simulation parameters through the monitoring data, it is necessary to
transform the disordered monitoring data into ordered data that can be converted into equal-step load
steps. Through the computer language program, the data is divided into bins and the average value of
each temperature bin is calculated. Subsequently, this paper uses the Douglas-Peucker algorithm to
compress the line elements[5], by retaining the data with typical characteristics to simplify the data, and
through the cubic spline interpolation, the data simplified by the DP algorithm is drawn A smooth data
development curve, through the curve trend and objective regularity trend development, to judge
whether the characteristic data taken can represent the data as a whole. The specific principles of this
data processing are as follows:

- Connect a straight line AB to the end of the data in the coordinate system, which is the chord of the curve
- Find the distance between all the points and the chord and find the point C with the largest distance from the section, and calculate the distance between it and the chord
- Compare the distance with the maximum error value of the monitoring meter. If it is less than the maximum error of the monitoring meter, the first two points are the characteristic points of the monitoring data; if it is greater than the maximum error of the monitoring meter, use C to divide the curve into two paragraphs AC, BC, repeat the above steps
- Take the processed data point set within a reasonable range, respectively complete the approximate curve through cubic spline interpolation, compare the approximate curve with the objective development law and the original data point and dash line, and take the reasonable approximate curve as the fitting curve. Monitoring data analysis, corresponding points are used as characteristic points for data data review

In figure 1 is the approximate curve generated by a warehouse of concrete after the generated processing.

![Figure 1. Time history chart of monitoring temperature after treatment.](image)

After processing, the characteristic points can be approximately converted into simulation calculation load steps for review, so as to optimize the simulation calculation results.

3.2. Simulation parameter review and optimization

The purpose of engineering site inversion is to provide a good basic platform for construction feedback calculation, and feedback calculation is to provide theoretical and technical guidance for the next stage of engineering construction. The quality of the on-site inversion result will determine the feedback calculation. Whether it is reliable or not will also play a key role in the construction quality of the project. Therefore, concrete engineering back analysis and construction feedback calculations usually need to be carried out in a rigorous manner, and the monitoring data information converted into corresponding load steps is brought in for review and optimization. The simulation compound optimization process designed in this paper is shown in figure 2:
Figure 2. Schematic diagram of simulation parameter review and optimization process.

It can be seen from the above that construction inversion and feedback calculation is an iterative process. The ultimate goal is to make the calculation model and parameters more accurate and precise, so that the simulation calculation can better reflect the actual engineering, and more targeted and rationalized Suggestions and temperature control measures.

3.3. Optimization analysis of concrete thermal parameters

This article will take concrete thermal parameters as an example, and combine with the engineering example to optimize the engineering simulation calculation. This calculation is based on a finite element simulation system[6], using the corresponding coagulation temperature stress model, mainly considering the impact of concrete cooling during the construction period, self-hydration heat release, and external environmental influences on the concrete temperature. For the optimization of concrete thermal parameters, the project has not yet stored water during the calculation period, and the impact of water storage on the project is not considered.

The design values of the initial thermal parameters in the simulation are as follows, and the key thermal parameters are analyzed and optimized respectively.

| Table 1. Initial thermal parameters of concrete. |
|-----------------------------------------------|
| Adiabatic temperature rise | Heat release coefficient $m_1$ | Heat release coefficient $m_2$ | Correction factor | Surface heat dissipation coefficient | Thermal Conductivity |
|---------------------------|---------------------------------|---------------------------------|------------------|-------------------------------------|---------------------|
| 23°C                      | 0.3                             | $10^{-1}m_1$                    | 0.6              | 196kJ/m²d°C                         | 156.72kJ/(md°C)     |

After substituting the process in figure 2, the concrete optimization parameters of each area are as follows:
Table 2. Optimized value parameters of concrete.

| Concrete partition | Adiabatic temperature rise | m1  | m2 | Correction factor |
|--------------------|---------------------------|-----|----|------------------|
| Initial value      | 23°C                      | 0.3 | m1/10 | 0.6              |
| C40 zone           | 24.5°C                    | 0.37| 0.03| 0.55             |
| C35 zone           | 22.3°C                    | 0.39| 0.03| 0.55             |

The comparison between the calculation results and monitoring after optimization of the concrete simulation parameters in the C35 area is in figure 3:

![Figure 3. Comparison of simulation value and monitoring value.](image)

It can be seen from the above figure that the relevant parameter inversion results after optimization can better reflect the early hydration heat release process of the low-heat cement concrete of the dam. As the pouring progress of the project progresses, there will be more monitoring data available for simulation. At this time, the closed-loop simulation optimization calculation scheme mentioned in this article can be further optimized by computer programs to make the calculation results closer to the real results.

4. Conclusions
The temperature and stress of concrete is a relatively complex problem, especially in mass concrete, there are many factors that affect the temperature of the concrete. The proper selection of parameters related to temperature and stress will directly affect the results of temperature simulation calculations' reliability and even success or failure. In this paper, the field measured values are used for parameter inversion analysis, and the field temperature calculation parameters are directly obtained. Based on a set of simulation calculation system, the simulation parameters are optimized by coupling the real-time updated monitoring data, and a set of closed loop system is formed to make the simulation calculation results. Better adherence and practicality, to meet the understanding of the working status of the arch dam construction process.

Due to the current transition from digital dams to smart dams, comprehensive perception, real-time transmission, and intelligent processing have gradually become a reality, and monitoring data can be processed through computers from acquisition to processing, which greatly simplifies the difficulty of data processing[7]. The method of using actual monitoring data to continuously invert and optimize the
simulation calculation model discussed in this paper will meet the needs of engineering construction into the 4.0 new era[8], and will become the mainstream of engineering academia.

Acknowledgement
The authors are grateful for the financial supports of National Natural Science Foundation of China (No. 51839007) and China Three Gorges Corporation Research Project (No. BHT/0809).

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