Construction Simulation and Real-time Monitoring Research of Concrete Dam Based on BIM

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Abstract: Concrete is a complex multiphase composite. Along with the hydration reaction, the thermal and mechanical properties of concrete continue to increase, resulting in deformations such as temperature, autogenous volume and shrinkage, and stress and creep after being restrained by themselves and externally, further cracks are formed. Through finite element simulation, the key parts of temperature control and crack prevention of concrete dam can be predicted, and targeted crack prevention measures can be proposed. Therefore based on BIM technology and combined with simulation results, this paper conducts real-time monitoring of concrete temperature and stress during construction. Through comparison and inversion analysis, the whole process dynamic management of temperature and stress during dam construction period is implemented, and temperature control measures are optimized in real time to realize the whole process control of temperature control and crack prevention of concrete dam.

1. Introduction
Many scholars have carried out related research in the construction of concrete dam temperature simulation and anti-cracking. Z.P.Bazant et al. made breakthroughs in concrete adiabatic temperature rise, shrinkage deformation and crack mechanism through years of experimentation and theoretical research.[1-2]. In China, academician Zhu Bofang systematically studied the temperature control and crack prevention of concrete through a large number of theories, algorithms and applied research [3]. Through the three-dimensional temperature field and stress field simulation calculation program, the concrete process and all factors of the concrete dam construction can be accurately simulated, which can understand the true stress state of the dam body to the greatest extent, and solve the crack cause and construction prevention of the concrete dam during the construction period and the initial operation period.

In recent years, with the development of BIM technology, through the systematic management of concrete construction procedures and temperature control measures, the accuracy of simulation calculation and construction management can be further improved, and the level of safety production management is guaranteed [4]. At present, the application of BIM technology in water conservancy projects has been gradually deepened, and the integration research with real-time monitoring is becoming maturer. Liao Zhenan et al [5] developed a large-volume concrete intelligent temperature control system based on BIM series software; Xue Xianghua [6] explored the main applications and advantages of BIM technology in all stages of the reservoir project. Based on the traditional dam construction period temperature monitoring method, this paper uses BIM technology to simulate the whole process of Qianming Reservoir construction, and carries out monitoring visualization research.
to realize the finite element simulation results in the design stage and the monitoring results demonstration in the construction period on the three-dimensional model.

2. Monitoring analysis during construction period

2.1. Real-time temperature monitoring and analysis

At the current stage of water conservancy construction, in order to understand the internal temperature change of the concrete in real time, a thermometer is buried in the interior and surface of the pouring layer to monitor the internal temperature of the concrete in real time. At the same time, based on genetic algorithm, a reliable adiabatic temperature rise model is established to invert the thermal parameters of different surface insulation materials, which can improve the simulation accuracy of concrete temperature field [7-8].

According to the comparative analysis of concrete temperature and fitting values during the construction period of Qianming Reservoir, as the cement hydration reaction heats up, the concrete temperature rises first and then falls, the interior of the pouring layer is less affected by the ambient temperature, and the temperature process line is basically stable; the external environment is greater affected by the ambient temperature, and the temperature is fluctuating with the air temperature. During low temperature season construction, the pouring temperature and ambient temperature are lower, the maximum temperature inside the concrete is about 33 °C, the measured and fitting peak values are basically the same, the peak appears on the 4th day after pouring; the concrete surface temperature rise is small, the highest temperature is about 25 °C, and fluctuating with air temperature. Based on the on-site measured temperature inversion, the surface inversion results of concrete surface heat exchange coefficient $\beta$ under different surface insulation measures are shown in Table 1.

### Table 1. Thermal parameters of concrete surface with different surface insulation measures.

| Board                     | Steel Board | Steel Board + 1.0cm Insulation board | Steel Board + 2.0cm Insulation board | Steel Board + 3.0cm Insulation board | Steel Board + 4.0cm Insulation board |
|---------------------------|-------------|--------------------------------------|--------------------------------------|--------------------------------------|--------------------------------------|
| $\beta$ [kJ/(m²·h·°C)]   | 30.3        | 18.2                                 | 15.4                                 | 13.2                                 | 11.6                                 |

2.2. Real-time monitoring and analysis of stress and strain

During the construction period, in order to understand the internal temperature and strain of the concrete in real time, a three-way strain gauge and a stress-free gauge are arranged inside the casting layer for real-time stress and strain monitoring. According to the finite element increment theory of elastic creep, the strain increment under complex stress state includes constrained strain increment, creep strain increment, temperature strain increment and autogenous volume strain increment, ie [3]

$$\Delta \varepsilon = \Delta \varepsilon^c + \Delta \varepsilon^c + \Delta \varepsilon^T + \Delta \varepsilon^a$$

formula, $\Delta \varepsilon^c$ is the constraint strain increment; $\Delta \varepsilon^c$ is the creep increment; $\Delta \varepsilon^T$ is the temperature strain increment; $\Delta \varepsilon^a$ is the autogenous volume strain increment.

We usually use a stress-free gauge to measure the temperature, autogenous volume, shrinkage and creep of concrete (Fig. 1). After pouring, the concrete volume expands with the increase of temperature, the total strain of the strain-free strain is tensile strain, and the maximum tensile strain is 58.7με; after 3 days of age, with the increase of concrete self-generated volume, dry shrinkage, etc., the tensile strain of the stress-free gauge decreases and gradually changes to shrinkage strain. After 30 days of age, the deformation of the concrete self-generated volume changes little, and the total strain changes mainly according to temperature.
In addition, the stress gauges are arranged in the left and right bank direction to measure the internal strain of the transverse river to the concrete. Strain gauge strains include strains due to stress strain, temperature strain, autogenous volume deformation, and creep (Figure 2). The temperature rises and the concrete expands, and the temperature strain is tensile strain, up to about 200 με (6 days old). The autogenous volume is deformed to contraction strain, up to about -180 με (40 days old). The stress strain is mainly the strain caused by the deformation of the concrete and the foundation. The stress strain is mainly the shrinkage strain, which is about -200με (6 days old). Thereafter, as the temperature decreases, the temperature expansion deformation decreases, and the stress strain value gradually decreases.

3. Temperature and stress simulation during construction period

3.1. Calculation model and parameters

Before construction, the finite element analysis can analyse the key parts of the temperature control and crack prevention of the dam. The construction simulation calculation is carried out with the typical dam section of Qianming Reservoir as the research object. Since the temperature stress is a self-balancing system, its influence mainly occurs in the intense temperature change and the basic restraint area. The depth of the dam body to the foundation temperature is generally less than 30m. Therefore, the dam foundation calculation domain takes 40m upstream of the dam and downstream of the toe of dam, and the foundation depth is 40m. The three-dimensional finite element simulation calculation model is shown in Fig. 3.
According to the concrete mix ratio and adiabatic temperature rise test of Qianming Reservoir, the thermal and mechanical parameters of concrete are shown in Table 2.

Table 2. Concrete thermal and mechanical parameters.

| Parameter                      | Value                      |
|--------------------------------|----------------------------|
| Adiabatic temperature rise °C  | 21.88(1−e^{−0.74τ/10})    |
| thermal diffusivity m²/h       | 0.003                      |
| Specific heat kJ/(kg·°C)       | 0.95                       |
| Autogenous volume deformation 10⁻⁶ | −14(1−e^{−0.076τ/10})     |
| Linear expansion coefficient 1/°C | 8x10⁻⁶            |
| Creeping relaxation coefficient 10⁻⁶ | 0.5              |

3.2. Simulation calculation result

In the simulation calculation process, according to the on-site construction management situation, the cosine function is used to fit the on-site air temperature. In order to control the temperature difference between the inner and outer parts of the concrete and the temperature difference between the concrete, the concrete pouring temperature is controlled at about 12 °C in winter; the concrete pouring temperature is about 18 °C in spring and autumn; in the high temperature season, the concrete pouring temperature is controlled to exceed 25 °C by measures such as ridge and ice water mixing. In the basic restraint zone, the thickness of the controlled casting layer is 1.5 to 2.0 m, the unconstrained zone is 3 m, and the interval between the layers is 10 to 15 days.

According to the three-dimensional finite element simulation calculation, in the low temperature season, the temperature is about 10 °C, the concrete pouring temperature is about 15 °C, the maximum internal temperature of the concrete is about 34 °C, the base temperature is 18 °C, and the internal and external temperature difference is about 14 °C. In spring and autumn, the temperature is about 20 °C. The measures such as ridge and ice water mixing are adopted to control the temperature of the concrete into the warehouse at about 24 °C. The maximum temperature inside the concrete is about 42 °C, the temperature difference between the inside and the outside is about 10 °C, and the temperature difference is about 24 °C. In the hot season, the temperature reaches 25~30°C, and the maximum daily maximum temperature can reach 40°C. At this time, the maximum internal temperature of the poured concrete can reach 47°C. Therefore, the hot season is the most critical period for construction crack prevention. Strict temperature control and crack prevention measures must be taken, and concrete pouring in the foundation restraint area should be avoided.
Figure 4. Distribution of cross-section temperature and principal stress $\sigma_1$ of dam body during low temperature season.

Figure 5. Distribution of cross-section temperature and principal stress $\sigma_1$ of dam body during spring and autumn.

4. Visualization management of Construction based on BIM

4.1. Parametric modeling
BIM technology provides a good platform for reservoir engineering visualization management. Based on the BIM series software, a three-dimensional model of the Qianming Reservoir dam was built, and information such as monitoring instrument embedding and construction methods was given to the model. Combined with three-dimensional finite element method simulation calculation and real-time monitoring data of construction period, it is integrated into BIM-based dam construction temperature control measurement model. Through the construction simulation, data display and other means, the image-based information visualization can be realized, providing effective technical support for three-dimensional display, construction guidance and project handover. The modeling uses Revit software platform, adopts parametric modeling to add component parameters, reduces the modeling workload, and imports the family diagram into the project and assembles it into a whole according to the positioning, by matching the three-dimensional model coordinates of the dam to fit the imported topographic map. The three-dimensional model in Revit is shown in Figure 6.
4.2. Construction simulation and visual management

BIM-based construction visualization management is to construct a four-dimensional construction simulation model that can be used for all-round display by simulating the time dimension to the three-dimensional model to simulate the whole process of dam concrete pouring. It can be used to check the irrationality of construction period and construction plan, master the internal temperature change of concrete in real time, optimize construction technology and temperature control and crack prevention measures. Modeling uses the Autodesk Navisworks Timeliner module. With the interaction of external programs such as Excel or Project, the Concrete pouring schedule is used as a time parameter to correspond to each block of the three-dimensional model that has been segmented, and a link is established, and the pouring start and end time, simulation results and measured temperature are given, in this way construction schedule control and temperature control real-time monitoring can be realized.. The simulation of the construction process made by Navisworks is shown in Figure 7.

Figure 7. Simulation of construction process.

Thermometers and strain gauges are buried inside the pouring layer of Qianming Reservoir to monitor the temperature and strain of the concrete during the whole process. In order to effectively combine the finite element simulation and actual measurement data in the design stage to lay a solid foundation for engineering construction safety, BIM technology can be used to import the calculation conclusions and measurement results into the constructed 3D model to realize the dynamic collection of temperature and stress during construction and four-dimensional visualization of hazardous areas. According to the position distribution of the monitoring instrument, based on Revit, the thermometer, the stress-free meter and other components are added in the corresponding pouring position, and the parameter information is added according to the actual situation. The design stage finite element calculation cloud map and dam safety monitoring process line diagram are imported into the BIM model as an external link in Navisworks, and the corresponding family files are tagged. Select each
position of the model, and separately view the theoretical value of the dam design stage under the corresponding part and the actual monitoring value cloud map to realize the four-dimensional visualization of the monitoring information, as shown in Figures 8 and 9. Through monitoring the matching of information data, the temperature index of the dam construction period is monitored in real time, and the control of the construction progress is guided.

5. Conclusions

In this paper, BIM technology is used to monitor the internal temperature and stress strain of the pouring block during construction, and the thermal parameters of the thermal insulation material are back analyzed. At the same time, based on the three-dimensional finite element calculation program, the temperature field and stress field of the Qianming Reservoir dam during construction are simulated. Study the key parts of temperature control and crack prevention of concrete construction in different seasons, so as to further improve the simulation calculation progress and optimize the construction plan and crack prevention measures. The research shows that on the basis of temperature field and stress simulation calculation, the temperature of the dam construction period is monitored in real time through BIM technology, and the four-dimensional temperature and stress strain prevention and control supervision is carried out. While improving the concrete construction progress, it effectively reduces the occurrence of cracks during the construction period and provides an effective guarantee for the safe operation of the dam.

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