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Computer simulation analysis of rock fill concrete gravity dam temperature field without transverse working condition

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Abstract: *In this paper, the computer simulation temperature field distribution of Jingshan rock fill concrete gravity dam is studied, and computer simulation analysis is carried out based on two schemes: no temperature control measures and simple temperature control measures. The computer simulation results show that the temperature of the dam body begins to rise with the increase of air temperature. With the increase of elevation, the dam body becomes thinner, and the computer simulation temperature inside the dam body changes periodically with the air temperature. Under the condition of simple temperature control measures, the distribution law of the dam body computer simulation temperature field is basically consistent with that without temperature control measures, and the computer simulation overall temperature value decreases slightly, but it is still unable to ensure that the dam concrete will not crack. It is necessary to further study the implementation plan of the dam body joint division and temperature control measures.*

Keywords: *computer simulation analysis; rock fill concrete; gravity dam; transverse*

1. Introduction

For mass concrete construction, temperature control and crack prevention are very important. Research has shown that rockfill concrete has lower hydration heat than normal concrete, which is conducive to temperature control. The adiabatic temperature rise is only about 15 ℃, which can simplify the temperature control measures, but this does not mean that the rockfill concrete does not need temperature control measures. RCC dams also have the advantage of low hydration heat [1-3].

Early RCC dams rarely took temperature control measures, but many cracks occurred in the project. In recent years, conventional temperature control measures such as cooling water pipes are commonly used in RCC dams [4-5]. However, for rockfill concrete dams, due to the large particle size of aggregate and the throwing of rockfill body will damage the pre laid cooling water pipe, it is difficult to carry out conventional temperature control measures such as water cooling and aggregate pre cooling [6].

To sum up, although rockfill concrete dam has the advantages of low temperature rise, whether it needs temperature control measures and what kind of temperature control measures to take are still problems to be solved.

2. Basic theory of concrete temperature field simulation

The global governing equation of the temperature field can be obtained from the stationary condition of the functional:

$$[H]\{T\}+[R]\left\{\frac{\partial T}{\partial t}\right\}+\{F\}=0 \tag{1}$$

The backward difference method is used for discretization in the time domain, and

$$\left(H+\frac{1}{\Delta t_n}R\right)T_{n+1}-\frac{1}{\Delta t_n}RT_n+F_{n+1}=0 \tag{2}$$

Where:

$$H_{ij}=\sum_e (h_{ij}^e+g_{ij}^e) \tag{3}$$

$$R_{ij}=\sum_e r_{ij}^e \tag{4}$$

$$F_i=\sum_e\left(-f_i^e-p_i^e\right) \tag{5}$$

3. Overview of Jingshan Gravity Dam

The main retaining dam of the project is a rockfill concrete gravity dam. The normal pool level is 81.00m, the dam crest elevation is 83.0m, the dam crest width is 6m, and the total dam crest length is 305m.The upstream face of the dam is vertical above the elevation of 67.0m, and the slope below the elevation of 67.0m is 1:0.2.The downstream face of the dam is vertical above the elevation of 80.0m, and the slope below the elevation of 80.0m is 1:0.7.According to the basic geological conditions of the riverbed section, the lowest foundation surface elevation of the riverbed is 54.0m, the maximum dam height is 29.0m, and the maximum bottom width of the dam is 26.4m.The upstream and downstream of the dam body are provided with cogging. The elevation view of the downstream of the main dam is shown in Fig. 1, and the profile of the non overflow dam is shown in Fig. 2.

The overflow dam section is arranged at the 0+070~0+085 section of the dam crest, with a length of 15m.The overflow weir is a surface outlet overflow controlled by a gate, and the weir crest elevation is 77.8m.The net width of the single hole of the overflow weir is 5.0m, with two holes. The middle pier is 2m wide, and the side piers on both sides are 1.5m wide.The underflow energy dissipation mode is adopted. The overflow surface of the main dam is connected with the bottom plate of the downstream stilling basin by an arc with a radius of 6m.The stilling basin is 30m long, 3.0m deep and 2.0m thick.20m long concrete apron is set behind the stilling basin.The profile of the overflow dam is shown in Fig. 3.

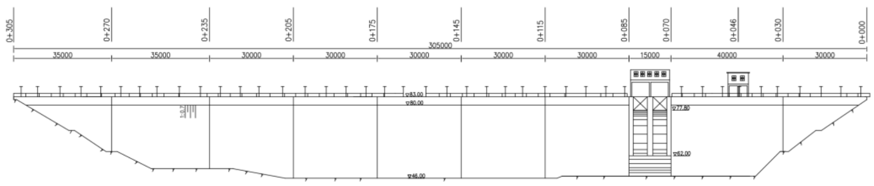

Figure 1: Elevation View of Downstream Main Dam

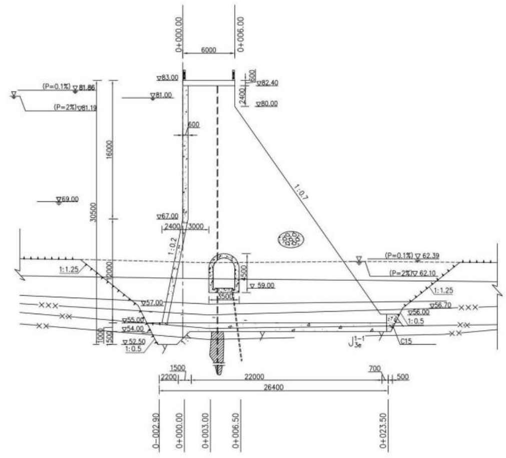

Figure 2: Profile of Non overflow Dam (0+150)

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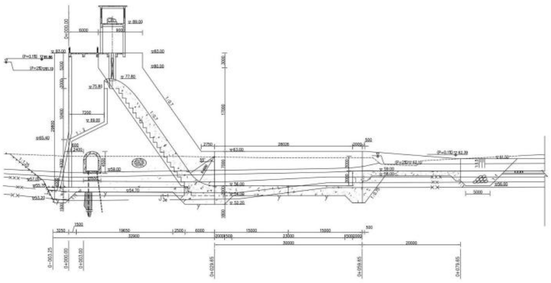

Figure 3: Profile of Overflow Dam(0+077.5)

This simulation mainly analyzes the temperature field of Jingshan gravity dam.Simulate the whole process of the dam body from August 11, 2021 to August 10, 2025, from the construction period, the storage period to the operation period.

The finite element model is shown in Fig. 4. The corresponding finite element grid has 60551 elements and 70638 nodes.The joint unit distribution of upstream anti-seepage plate is shown in Fig. 5. The dam body is not provided with transverse joints.

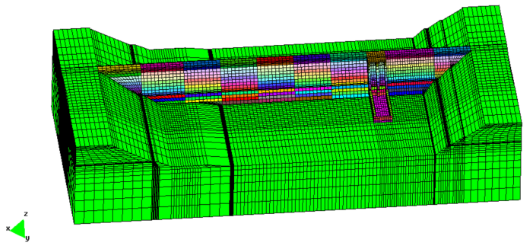

Figure 4: Finite element model

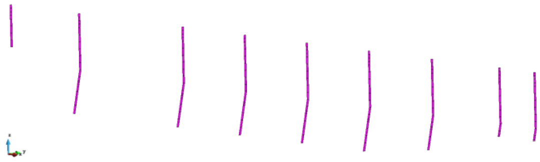

Figure 5: Joint unit distribution

In order to analyze the temperature and stress variation law of the dam body, the middle section (X=130) of No. 5 dam section is selected as a typical section. Three typical elevations of typical sections are taken as representative elevations in this project, which are 57m (near the bottom of the dam), 67m (near the middle of the dam), and 82m (near the top of the dam).For each typical elevation, three typical points are taken for analysis, namely, the upstream dam surface point, the dam interior point, and the downstream dam surface point. Typical point locations are shown in Fig. 6.

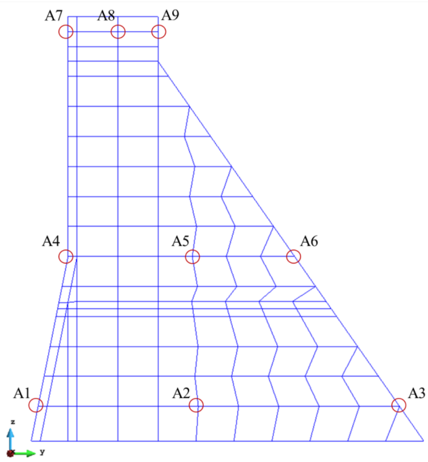

Figure 6: Typical Point Location

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4. Simulation analysis of temperature field of Jingshan gravity dam

The simulation calculation lasts 1440 days from August 11, 2021, the construction start time, to August 10, 2025, the operation period.

The annual average temperature of Jingshan Reservoir is 17.8 ℃, and the annual average temperature variation is 21.4 ℃. The cosine function is used to fit the annual temperature change.As the water depth in the upper reaches of the reservoir is small, it can be simplified as the annual average water temperature is constant along the water depth, and they are all reservoir surface water temperature values.With reference to similar projects, the reservoir surface water temperature is 1 ℃ higher than the annual average temperature, taking 18.8 ℃. Thermal and mechanical parameters of concrete and bedrock is shown in Table 1.

Table 1: Thermal and mechanical parameters of concrete and bedrock

Parameter	C20 concrete	C20 rockfill concrete	Bedrock
Elastic Modulus (GPa)	25.5	38.5	6.0
Adiabatic temperature rise(℃)	24.8	14.2	
Linear expansion coefficient ($\times 10^{-5}$/℃)	1.0	0.7	0.7
Specific heat (KJ/kg·℃)	0.96	0.872	0.749
Thermal Conductivity (KJ/m·d·℃)	254.4	301.4	348.7
Bulk density	24.5	24.9	26.0
Poisson's ratio	0.167	0.167	0.25

1) Simulation results of temperature field without temperature control measures

The temperature field of different working conditions without temperature control measures are shown in Fig. 7-10.

The dam body was poured in late June, and the temperature began to rise.As the thickness of the top layer of the dam body is only 6.0m, the newly poured concrete is significantly affected by the temperature. The hydration heat cannot be dissipated through the dam surface, and a high temperature zone is formed on the top of the dam body.The high temperature area is still concentrated in the middle upper part of the dam body, and the maximum temperature in the high temperature area is about 29.1 ℃ at this moment.Before the impoundment (mid August 2022), the internal temperature and surface temperature of the dam body have a large difference, which has formed an obvious gradient.After impoundment, the water depth in the upstream is 27.0m, there is no water in the downstream, and the dam surface is exposed in the air.As the upstream water depth is small, the reservoir bottom and water depth surface temperatures are considered consistent in this working condition, so the upstream dam surface temperature does not show stratification.As the dam body is thin, the maximum thickness of the bottom is 26.4m, and the thickness of the top is only 6.0m, the temperature field inside the dam body is greatly affected by the temperature.By the middle of January 2025, the upstream surface temperature of the dam body will be maintained at about 18 ℃ (water temperature).At this time, the downstream surface is exposed to the air, and the temperature is affected by the external temperature, about - 1.7 ℃.By the middle of July 2025, the upstream surface temperature of the dam body will be maintained at about 18 ℃ (water temperature).At this time, the downstream surface is exposed to the air, and the temperature is affected by the external temperature, about 35.9 ℃.

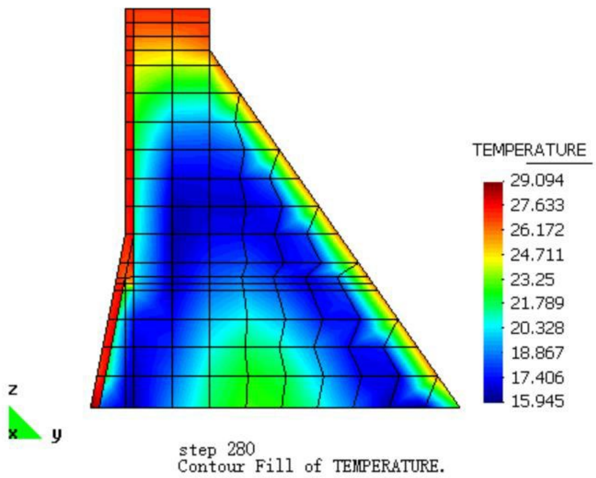

Figure 7: Temperature field upon completion of construction without Temperature Control Measures (late June 2022)

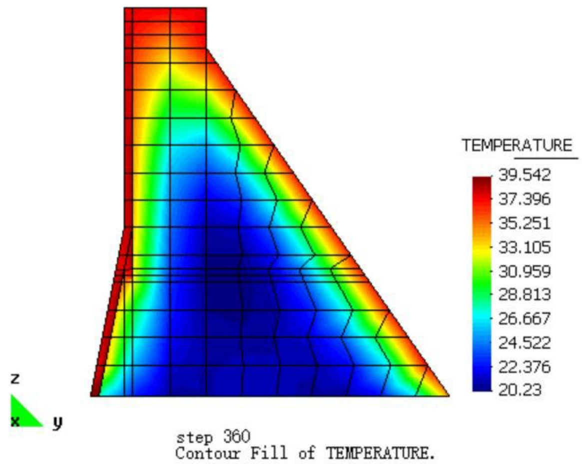

Figure 8: Temperature field before impoundment without Temperature Control Measures(mid August 2022)

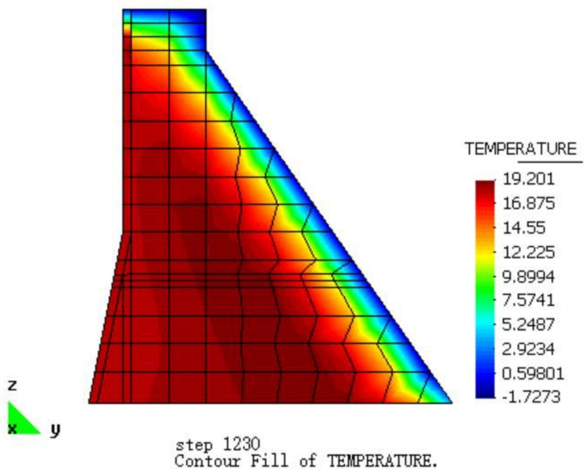

Figure 9: Temperature field during operation period without Temperature Control Measures(mid January 2025)

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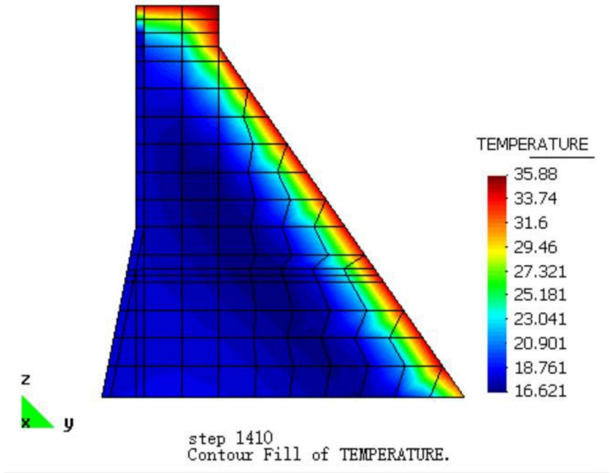

Figure 10: Temperature field during operation period without Temperature Control Measures(mid July 2025)

The time history curve of temperature field without temperature control measures are shown in Fig. 11.

The dam body is made of rockfill concrete with low hydration temperature rise, so the overall temperature of the dam body is low. The maximum temperature of the dam body is 34.2 ℃, which occurs at A2 point, mainly due to the high pouring temperature and air temperature at the bottom of the dam body.It can be seen from the figures that with the elevation rising, the dam body becomes thinner, and the temperature inside the dam body changes periodically with the temperature.

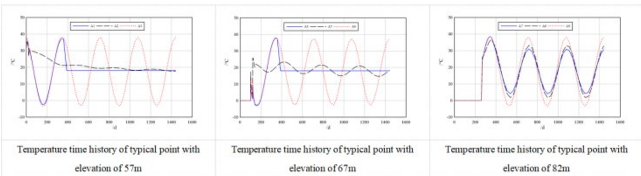

Figure 11: Time history curve of temperature field without temperature control measures

2) Simulation results of temperature field of Simple temperature control measures

Simple temperature control measures shall be taken: (1) When the average temperature of the day is less than 20℃, the pouring temperature is equal to the air temperature; when the average temperature of the day is higher than 20℃, the pouring shall not be carried out during the period when the air temperature exceeds 20℃, and the concrete pouring temperature shall be considered as 20℃;(2) Surface insulation measures shall be taken for the upstream surface, downstream surface and warehouse surface in the low temperature season (October 15 March 15) during the construction period before water storage, and the equivalent heat release coefficient shall be 15kJ/(m^2.h.℃).

The temperature field of different working conditions of simple temperature control measures are shown in Fig. 12-15.

As the thickness of the top layer of the dam body is only 6.0m, the newly poured concrete is significantly affected by the temperature. The hydration heat cannot be dissipated through the dam surface, and a high temperature zone is formed on the top of the dam body.The high temperature area is still concentrated in the middle upper part of the dam body, and the maximum temperature in the high temperature area is about 28.9 ℃ at this moment. As the temperature rises, the dam body temperature also starts to rise.Before the impoundment (mid August 2022), the internal temperature and surface temperature of the dam body have a large difference, which has formed an obvious gradient.After impoundment, the water depth in the upstream is 27.0m, and there is no water in the downstream. The surface of the dam body is exposed in the air. The temperature field inside the dam body is greatly affected by the temperature.By the middle of January 2025, the upstream surface temperature of the dam body will be maintained at about 18 ℃ (water temperature). At this time, the downstream surface is exposed to the air, and the temperature is affected by the external temperature, about - 1.7 ℃.By the middle of July 2025, the upstream surface temperature of the dam body will be maintained at about 18 ℃ (water temperature). At this time, the downstream surface is exposed to the air, and the temperature is affected by the external

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temperature, about 35.9 °C.

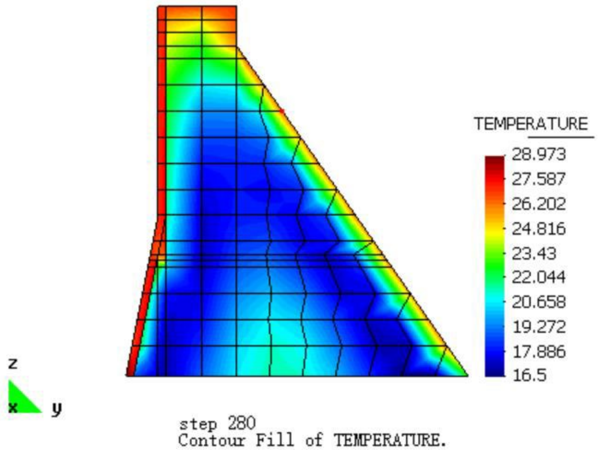

Figure 12: Temperature field upon completion of construction of Simple Temperature Control Measures (late June 2022)

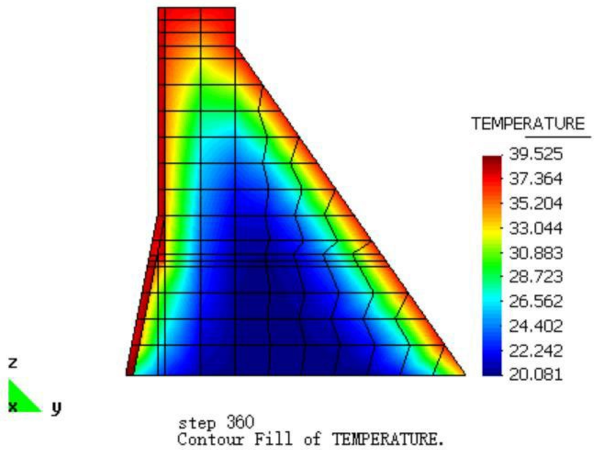

Figure 13: Temperature field before impoundment of Simple Temperature Control Measures (mid August 2022)

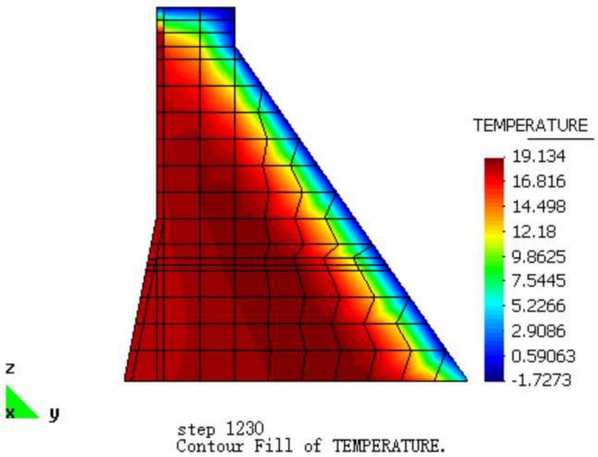

Figure 14: Temperature field during operation period of Simple Temperature Control Measures (mid January 2025)

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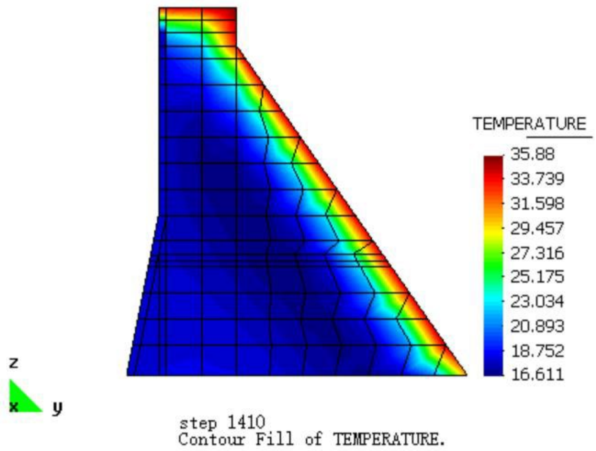

Figure 15: Temperature field during operation period of Simple Temperature Control Measures (mid July 2025)

The time history curve of temperature field of simple temperature control measures are shown in Fig. 16.

The dam body is made of rockfill concrete with low hydration temperature rise, so the overall temperature of the dam body is low. The maximum temperature of the dam body is 33.8 ℃, which occurs at A2 point, mainly due to the high pouring temperature and air temperature at the bottom of the dam body.It can be seen from the figures that with the elevation rising, the dam body becomes thinner, and the temperature inside the dam body changes periodically with the temperature.

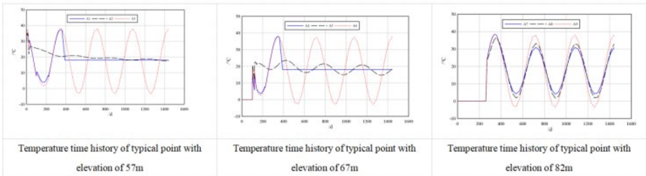

Figure 16: Time History Curve of Temperature Field of Simple Temperature Control Measures

5. Conclusion

This paper mainly studies the temperature field distribution of Jingshan rockfill concrete gravity dam, and analyzes and describes two schemes: never adopting temperature control measures and carrying out simple temperature control measures.

Through comprehensive analysis of temperature distribution map and time history curve, it can be concluded that the dam body temperature starts to rise with the increase of air temperature. With the elevation rising, the dam body becomes thinner, and the temperature inside the dam body changes periodically with atmospheric temperature.Under the condition of simple temperature control measures, the distribution law of the dam body temperature field is basically consistent with that without temperature control measures, and the overall temperature value decreases slightly, but it is still unable to ensure that the dam concrete will not crack.

Therefore, it is necessary to further study the implementation plan of the dam body joint and temperature control measures to provide theoretical support for the safe operation of the project.

Acknowledgments

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