Discussion on Temperature Control Method of Cooling Water Pipe for Mass Concrete Construction

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Abstract: For studying the influence of cooling pipes on the mass concrete construction, the dam is taken an example to build the ANSYS finite element model. The model simulates dam concrete construction based on two projects, one without cooling pipes and the other with cooling water pipes provided. The data comparison and analyzing will be in three aspects: temperature, stress and displacement. The result shows that the cooling pipes not only can indeed reduce the concrete temperature in a short time, making the concrete reach the steady temperature more quickly, but also help to alleviate the concrete temperature stress. However, the reductions of temperature donot make a great influence on the displacement during the construction process.

1 Introduction

The temperature stress of mass concrete is the force generated by internal or external restrictions due to temperature changes and expansion or contraction of the corresponding structure after concrete is poured. Cracks caused by temperature stress have the characteristics of wide cracks and vertical penetration, which have a great influence on the bearing capacity 、 waterproof performance and durability of the structure. The method of reducing hydration heat can be divided into low-heat cement 、 segmented pouring 、 aggregate precooling 、 cooling circulating water pipes, and maintenance^[1]. Laying the cooling water pipe to cool and cool the concrete is one of the effective methods for temperature control measures of the dam. At the same time, the concrete can be cooled to a quasi-stable temperature in a short time, thereby improving the concrete construction speed.

The cooling water pipe cooling technology was first proposed by the US Bureau of Reclamation. Chinese scholars have far exceeded the research and engineering application of the stress field and strain field generated by cooling water pipes in foreign countries, and the depth and breadth of research are far ahead^[4]. The scholar, Mai Jiaxuan, combined the analytical method of the cooling water pipe with the finite element method to simplify the calculation and expand the research scope of the cooling water pipe. Professor Li Weichao conducted a field trial study of the cooling water pipe during the construction of the Three Gorges Project and obtained excellent research results. Professor Zhu Yueming and Professor Zhang Jianbin carried out the application of cooling water pipes in the construction of Ertan Arch Dam and Dachao

Mountain Cofferdam respectively and discussed them in depth^{[2]-[9+11]}.

In this paper, the finite element analysis software ANSYS is used to simulate the concrete pouring process of a large-volume concrete dam under two different conditions: conventional water-free and cooling water-passing water. The variation of temperature, stress and displacement is compared, and a useful conclusion is obtained. High quality and efficient construction of mass concrete provides theoretical and technical support.

2 Basic theory

The equivalent heat conduction equation of the cooling water pipe is adopted, and the cooling water pipe is taken as the heat sink. The cooling effect of the cooling water pipe is considered in the average sense, and the equivalent heat conduction equation 1:

$$\frac{\partial T}{\partial t} = a \left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} \right) + (T_0 - T_w) \frac{\partial \phi}{\partial t} + \theta_0 \frac{\partial \Psi}{\partial t} \quad (1)$$

Among them:

T: Concrete temperature t: time a: Concrete temperature coefficient

T₀: Initial temperature of concrete; T_w: Water inlet water temperature;

θ₀: Final adiabatic temperature rise φ&Ψ: Water pipe cooling effect function

The effect of creep on concrete is mainly to eliminate the internal temperature stress and shrinkage stress of concrete and reduce concrete cracking. Therefore, the equivalent principle can be used to classify the creep into elastic deformation, which is to transform the creep into a fairly elastic problem. The creep is mainly to reduce the elastic modulus of concrete. However, since the elastic

modulus is continuously increased after the concrete is poured, the elastic modulus of the concrete should be the effective elastic modulus E^* , C is a creep function, and E is the original concrete elastic modulus.

3 Project example

Taking the construction process of the middle 2 dam section (partial) of a large-volume concrete dam as an engineering case study, the dam body is poured according to the cooling water pipe layout scheme and the conventional water-free scheme, respectively, corresponding to the thermal analysis and stress field from the temperature field. Force analysis and displacement are compared. The water-passing conditions are arranged according to the horizontal and vertical spacing of $1\text{m} \times 2\text{m}$, the cooling water temperature is 5°C , the water is uninterrupted for 10 days immediately after the concrete is poured, and the 2.54cm diameter water pipe is arranged at a height of 0.5m per layer of the casting layer, and each A row of cooling water pipes is arranged in a casting layer. The concrete pouring of the dam body starts from the second half of September to the beginning of the next summer. The ambient temperature drops from 23°C to 7°C and then

rises to 19°C . The concrete pouring temperature is equal to the local outside temperature. If the temperature is too low, the insulation is taken to make the concrete. The pouring temperature is not lower than 15°C . The concrete pouring method is poured upwards on the whole layer of 2m and 10 days, and the foundation of the dam body does not exchange heat with the soil, which is set as adiabatic condition; The top surface and the upstream and downstream surfaces of each layer of poured concrete are set to be convective heat exchange boundary with air; the concrete is in good contact with the foundation and the heat transfer is continuous. The model sets the ambient temperature change function, and the construction process can be completed by using the unit life and death function of ANSYS. For the specific operation of Large-scale concrete cooling water pipe foundation construction^[12], Early thermochemical mechanical cracking assessment of large concrete structures^[13], Hydraulic mechanism of reinforced concrete and numerical simulation^[14]. The indirect method is used in the simulation calculation, The temperature field thermal analysis is performed first, and the temperature data result is obtained and derived, and then the stress field analysis is performed, and the temperature data is directly introduced as a load.

Figure 1. Schematic diagram of water pipe layout (top view and front view)

Table 1. Material parameters

Parameter	Unit	Bedrock	Concrete
Thermal Conductivity	$\text{kJ}/(\text{m} \cdot \text{d} \cdot ^\circ\text{C})$	206.35	240
Specific heat	$\text{kJ}/(\text{kg} \cdot ^\circ\text{C})$	0.967	1.01
Density	kg/m^3	2721	2455
Poisson's ratio	--	0.28	0.167
Linear expansion coefficient	$1/^\circ\text{C}$	10×10^{-6}	10×10^{-6}
Linear expansion coefficient	GPat	5	$E(\tau) = 32(1 - e^{-0.55\tau^{0.4}})$

Figure 2. Finite element model of concrete dam

3.1 Temperature field temperature analysis

During the simulation, the concrete began to experience a large temperature rise and a gradual cooling and cooling process starting from the pouring temperature. From the results, the center point of the third layer of concrete pouring layer was extracted as the research object, and the concrete temperature change process was observed. The temperature at the center point is compared with the following figures under two different conditions: no water and no water. It can be seen that under the condition of 10 days of water passing, the concrete not

only drops by about 5.65°C on average, but also reaches the stable temperature of the concrete faster. In the absence of water, the concrete dam body temperature remains high for a long time after pouring, and the external temperature has been decreasing. The large temperature difference will cause large temperature stress, which greatly affects the joint construction work of the dam body. From the perspective of temperature change, it can be seen that the use of cooling water pipes can effectively cool the concrete temperature and improve the efficiency of concrete construction work.

Figure 3. (left) temperature comparison under no water and (right) water conditions ($T/^{\circ}\text{C}$)

Figure 4. Temperature comparison of two different conditions

3.2 Stress field analysis

Corresponding to the three directions of X、Y and Z axes in the finite element model of concrete dam in Fig 2, namely, the direction of river flow, the vertical direction of dam and the direction of vertical river flow, respectively, the third concrete under different conditions is discussed. The force of the concrete center point of the pouring layer. Set the direction of the force so that the tensile stress is positive and the compressive stress is negative.

In the direction of the X-axis (flow direction of the river), Although the internal force of the concrete will decrease after the water is passed, the tensile stress is caused by a large temperature difference near the water pipe. The tensile stress is still less than the tensile limit and center point of the concrete. The overall simulation results are shown in Figure 3; The direction of the Y-axis (vertical direction of the dam) is mainly based on the self-weight of the concrete, and the temperature stress is only a part. The temperature difference is eliminated by the water pipe to reduce the force. The center point data is shown in Table 3 and the overall simulation results are compared 4; In the Z-axis direction (vertical flow

direction of the vertical flow), the force is also symmetrical due to the axisymmetric characteristics of the figure. Therefore, as shown in Fig. 5, the force is symmetrically distributed. However, at the same time, the selected point is located on the axisymmetric center plane of the model, and the table selects the data of the 1/2 model. However, in the overall model, there is still the same value of the other half of the surface, and the opposite direction of force causes the point to flow vertically in the direction of the river. The forces are offset by each other.

From the comparison of the flow direction of the concrete dam, the vertical direction of the dam and the direction of the vertical river flow, it can be seen that under the condition of using the cooling water pipe, the force at the center point is improved to some extent. This is because during the cooling process of the water, the water pipe absorbs the heat generated by part of the hydration heat, slows down the internal and external temperature gradient of the concrete, thereby reducing the internal temperature stress, and the maximum tensile stress is also reduced as shown in Table 5 and Figure 6. This has a positive effect on the improvement of concrete dam construction efficiency.

Table 2. Stress comparison under different conditions of river flow direction (MPa)

Age	No water	Water	Difference (%)	Age	No water	Water	Difference (%)
21	-1.5162	-1.3677	-9.79%	31	-1.1156	-0.5132	-54.00%
22	-1.8807	-1.8084	-3.84%	32	-1.2030	-0.8103	-32.64%
23	-1.9986	-1.8242	-8.73%	33	-1.2990	-1.0528	-18.95%
24	-2.0711	-1.8600	-10.19%	34	-1.4106	-1.2670	-10.18%
25	-2.0786	-1.8968	-8.75%	35	-1.5305	-1.2980	-15.19%
26	-2.2084	-1.9200	-13.06%	36	-1.6437	-1.3210	-19.63%
27	-1.9978	-1.7626	-11.77%	37	-1.7530	-1.3465	-23.19%
28	-1.9941	-1.6211	-18.71%	38	-1.8533	-1.3880	-25.11%
29	-1.8550	-1.4634	-21.11%	39	-1.9432	-1.4011	-27.90%
30	-1.8310	-1.4098	-23.00%	40	-2.0230	-1.4235	-29.63%
Average difference in water supply period: -12.90%				Average difference after passing water:-25.64%			

Table 3 Stress comparison under different conditions of dam body vertical direction (MPa)

Age	No water	Water	Difference (%)	Age	No water	Water	Difference (%)
21	-0.0007	-0.00238	240.00%	31	0.0207	0.0117	-43.48%
22	0.0066	0.0020	-69.70%	32	0.0456	0.0152	-66.67%
23	0.0114	0.0033	-71.05%	33	0.0639	0.0183	-71.36%
24	0.0133	0.0041	-69.17%	34	0.0742	0.0207	-72.10%
25	0.0150	0.0050	-66.67%	35	0.0802	0.0236	-70.57%
26	0.0161	0.0058	-63.98%	36	0.0836	0.0262	-68.66%
27	0.0170	0.0067	-60.59%	37	0.0852	0.0287	-66.31%
28	0.0176	0.0070	-60.23%	38	0.0858	0.0321	-62.59%
29	0.0180	0.0074	-59.44%	39	0.0859	0.0345	-59.84%
30	0.0183	0.0076	-58.47%	40	0.0861	0.0352	-59.12%
Average difference between waters: -33.93%				Average difference after passing water: -64.07%			

Table 4 Stress comparison under different conditions of vertical river flow direction (half side) (MPa)

Age	No water	Water	Difference (%)	Age	No water	Water	Difference (%)
21	-4.6349	-4.3388	-6.39%	31	-4.3790	-3.4844	-20.43%
22	-6.0466	-5.5030	-8.99%	32	-5.2862	-4.1338	-21.80%
23	-6.7931	-5.6791	-16.40%	33	-5.8724	-4.6303	-21.15%
24	-7.2201	-5.6822	-21.30%	34	-6.3198	-5.0514	-20.07%
25	-7.4734	-5.8328	-21.95%	35	-6.6846	-5.4018	-19.19%
26	-7.5823	-5.9564	-21.44%	36	-6.9908	-5.5923	-20.00%
27	-7.7196	-6.0001	-22.27%	37	-7.2513	-5.7750	-20.36%
28	-7.7720	-6.1230	-21.22%	38	-7.4747	-5.8846	-21.27%
29	-7.8020	-6.1811	-20.78%	39	-7.6649	-6.0040	-21.67%
30	-7.8491	-6.2283	-20.65%	40	-7.8240	-6.1843	-20.96%
Average difference between waters: -18.14%				Average difference after passing water: -20.69%			

Table 5 Maximum tensile stress (MPa)

Age	No water	Water	Difference (%)	Age	No water	Water	Difference (%)
21	-0.0004	-0.0022	450.00%	31	0.0211	0.0120	-43.13%
22	0.0070	0.0022	-68.57%	32	0.0471	0.0232	-50.74%
23	0.0121	0.0035	-71.07%	33	0.0671	0.0307	-54.25%
24	0.0137	0.0043	-67.88%	34	0.0757	0.0366	-51.78%
25	0.0155	0.0050	-67.74%	35	0.0817	0.0420	-48.59%
26	0.0168	0.0060	-64.29%	36	0.0851	0.0442	-48.06%
27	0.0175	0.0069	-60.57%	37	0.0868	0.0451	-48.04%
28	0.0181	0.0075	-59.12%	38	0.0873	0.0458	-47.54%
29	0.0186	0.0081	-55.91%	39	0.0880	0.0463	-47.27%
30	0.0189	0.0087	-53.97%	40	0.0884	0.0464	-47.40%
Average difference between waters: -11.91%				Average difference after passing water: -48.68%			

3.3 Displacement comparison

The maximum displacement of the concrete dam generally occurs on the top surface of the newly poured concrete, and the displacement values are from large to small, and are distributed from top to bottom. By comparing the above data, it is found that the use of a cooling water pipe reduces the temperature stress of the concrete, so that the displacement caused by the stress is

also reduced. However, during the whole construction period, the displacement of the concrete dam is mainly the weight of the concrete, and the displacement caused by the temperature stress only accounts for a small part, and the displacement change law does not change much. The details are shown in Table 6, Figure 11-12.

Table 6. Maximum displacement (mm)

Age	No water	Water	Difference (%)	Age	No water	Water	Difference (%)
10	5.928	5.694	-3.95%	130	9.808	8.917	-9.08%
20	6.667	6.327	-5.10%	140	10.080	9.140	-9.33%
30	7.414	6.933	-6.49%	150	10.352	9.364	-9.54%
40	7.886	7.313	-7.27%	160	10.738	9.705	-9.62%
50	8.337	7.677	-7.92%	170	11.059	9.983	-9.73%
60	8.755	8.029	-8.29%	180	11.363	10.247	-9.82%
90	8.751	8.093	-7.52%	190	12.012	10.841	-9.75%
100	8.971	8.249	-8.05%	200	12.474	11.257	-9.76%
Average displacement average difference: -8.37%							

4 Conclusion

In this paper, the finite element analysis software ANSYS is used to simulate the construction process of a large-volume concrete dam. According to the two different conditions of no water and cooling water, the temperature field and the stress field considering creep are successively calculated. The relevant conclusions are obtained:

(1) The use of cooling water pipes to cool down can actually reduce the internal temperature of the concrete, so that the concrete can reach the target stable temperature in a short time and accelerate the concrete construction work.

(2) The cooling water pipe absorbs the heat generated by part of the hydration heat, thereby reducing the temperature difference between the inside and the outside of the concrete, and the temperature stress is also correspondingly reduced, which better improves the internal stress conditions of the concrete.

(3) The cooling effect of the cooling water pipe has no obvious influence on the displacement of the concrete dam during construction. At this time, the displacement of the dam is mainly caused by its own weight, not the temperature stress.

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