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Autogenous Volume Deformation of Hydraulic Concrete

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Abstract

In hydraulic mass concrete construction, the autogenous volume deformation is a more important factor for concrete to generate adverse tensile stress, which will lead to structural cracks. The adverse effect of autogenous volume deformation of concrete will be offset by cooling pipe skills. That is, to make the volume deformation unchangeable or minimum after pouring, the autogenous volume deformation is set to be counteracted by moderate temperature expansion deformation. The simulation results show that the adverse effect of autogenous volume shrinkage deformation of concrete can decrease obviously by controlling cooling water during construction period. The results can provide certain references to hydraulic mass concrete rapid construction.

Keywords: autogenous volume deformation, mass concrete, cooling pipe, compensation of temperature inflation

1. Introduction

Autogenous volume deformation is adverse to the concrete's anti-cracking quality. The mass concrete structure will crack when the shrinkage deformation is superposed with the temperature deformation. Generally, autogenous volume deformation is in range of -100×10^{-6} -100×10^{-6} [1]. The linear expansion coefficient of the concrete can be considered as $10\times10^{-6}/°C$. The bigger autogenous volume deformation then can be equal to the deformation caused by dozens of degrees. It indicates that the influence of autogenous shrinkage of concrete to the crack of concrete can not be neglected. Tazawa.etc[2-3] studied autogenous volume shrinkage of concrete.

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In this paper, to make the volume deformation minimum after casting, the autogenous shrinkage is set to be counteracted by moderate temperature expansion deformation, when the using of pipe cooling, pouring temperature and the average temperature (quasi-steady temperature) are considered.

2. Principle and method of calculation

2.1 Basic theory and finite element method (FEM) of unstable temperature field

For every point in the research field R, the unstable temperature field T (x, y, z, t) must meet the heat conduction equations [4]:

$$\partial T/\partial t = a\left(\partial^2 T/\partial x^2 + \partial^2 T/\partial y^2 + \partial^2 T/\partial z^2\right) + \partial\theta/\partial\tau \tag{1}$$

Where T is the temperature function (℃), a the temperature conductivity (m^2/h), θ the concrete adiabatic temperature rise (℃), t the time function (d), τ the ages for concrete (d).

The Equation(1) is discrete in the domain R by using the variation principle and the spatial domain, finite difference time domain and introducing the initial conditions and the boundary conditions, the FE calculation recursive equation of the temperature field can be given as:

$$\left([H]+[R]/\Delta t_n\right)\{T_{N+1}\} - [R]\{T_n\}/\Delta t_n + \{F_{n+1}\} = 0 \tag{2}$$

2.2 Calculation principle and method for concrete temperature field with cooling pipes

According to the Fourier heat transfer law and the heat balance conditions, the increment of water temperature [5] along the pipe can be given as:

$$\Delta T_{wi} = -\lambda \iint_{\Gamma^0} \frac{\partial T}{\partial n} ds \Big/ c_w \rho_w q_w \tag{3}$$

where q_w, c_w, ρ_w are cooling water flow, specific heat and density respectively.

Since the inlet temperature of the cooling water is known in advance, the water temperature change in each cooling pipe along the flow direction can be amplified using the Equation(3). The water temperature change in each cooling pipes along the flow direction is relevant with the temperature gradient $\partial T/\partial n$. Thus, the concrete temperature field with cooling pipes is a typical nonlinear boundary problem and the iterative method is used to approach the true solution of the temperature field[6].

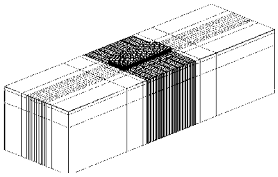
3. Numerical example

3.1 The FE model

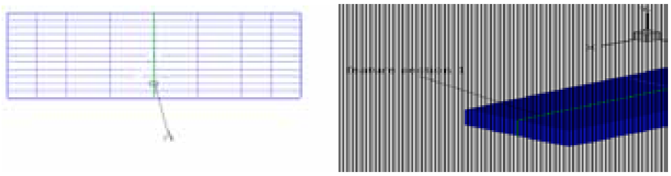
The meteorological data, the water temperature, the thermal and mechanical parameters can be seen from the some concrete gravity dam. In this FE model, the C35 concrete is chosen. The size of concrete block in the model is 60.0m in length, 20.0m in width and 6.0m in height while the size of bed rock is 260.0m in length, 80.0m in width and 100.0m in height. The model is 43569 nodes and 37792 elements, including the cooling pipes.

As shown in Fig.2, the feature point A with the coordinate (30,10,1) is located at the centre of the first lift. According to the practical experiences, the feature sections are chosen as the cross-section with higher temperature and the vertical section with higher stress.

In this study, it assumes that the lift is 2.0m in height and the intermission is 6.0 days. The sample of the cooling pipes in the model is shown in Fig.3: two pipe layers are set in every lift. The distance between two pipe layers is 1m and the distance between two pipes in the same lift is 1.0m. Meanwhile, the distance from the pipe to the surface is 0.5m and the distance from the top pipe to the surface is 0.35m.

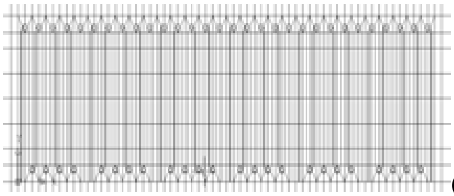


(a)

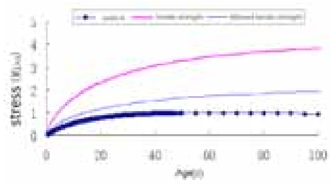


(b)

Fig.1 The FE mesh (a)
Fig.2The feature points and the feature sections (b)



(a)



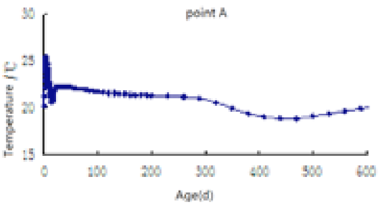
(b)

Fig.3 The type pipe net mesh (a)
Fig.4 Stress curve of point A under condition1 (b)

Three conditions are considered. Condition1: Consider only the influence of autogenous volume deformation. Condition2: Arrangement of cooling pipes in the concrete, initial import water temperature is 5℃ and durative 13days, also the initial flow rate is 1.2m/s and flow is 2.66m3 /s. Condition3: On the basis of condition 2, initial import water temperature is 12℃, and 10 days after the temperature is 16℃. Meanwhile, flow rate and flow decrease to half.

3.2 Analysis of the calculation results

In condition 1, the autogenous volume deformation is only taken into account. As shown in Fig.4, the maximum tensile stress, about 1.0MPa less than permitted tensile strength, appears at point A (centre of the first lift), which is produced by autogenous volume deformation at about 30.0th day.



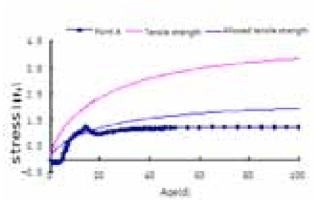


Fig.5 Temperature curve of point A under condition2

In condition 2, considering the crack of concrete under considerable tensile stress, the intensity of pipe cooling should be controlled at the early stage of concrete pouring. For there would be considerable tensile stress produced by excessive cooling while the tensile strength was low (For example: the tensile stress exceeded permitted tensile strength at the 7th day at point A.).

The peak of temperature reduced and the emergence came in advance after the water-cooling beginning (For example: the temperature peak appeared at the 5th day at point A. The internal suppressive stress decreased and rapidly transformed into tensile stress when the temperature reached peak (For example: The stress was suppressive stress before the 8th day while tensile stress after).

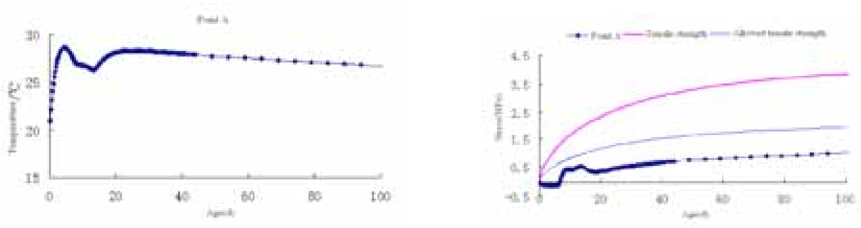


Fig.6 Temperature, stress curve of point A under condition 3

The temperature decreased rapidly under the effect of cooling water and became lower than the temporal environment temperature after the peak. The tensile stress was less and smaller than the permitted tensile strength, for the elastic modulus was small then. Under the effect of external temperature, the tensile stress, which came from inflation produced by internal concrete temperature rising, would offset the autochthonous volume deformation after cutting the water supply. Rational water-cooling system would be powerful in diminishing the later period concrete tensile stress.

4. Conclusion

(1)The autogenous volume deformation is a more important factor for concrete to generate adverse tensile stress. The simulation results indicated that a termination of about 60μ autogenous shrinkage could generate about 1.0MPa tensile stress maximally, at the early stage of concrete pouring (about 30d).

(2)This paper aimed at researching the compensation between thermal expending and autogenous shrinkage deformation. The optimum scenario from simulation results indicated that concrete temperature rise 2℃ when the water supply was cut at the 13th day, while the remaining autogenous shrinkage was about 20μ after 13d, basically fulfilling the purpose of deformation compensation.

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