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Simulation Analysis of Mass Concrete Temperature Field

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Abstract

The cracking phenomenon of mass concrete in the foundation mat of high-rise building is a key issue concerned by the engineering. The temperature control of mass concrete has great significance in assuring the project quality. At present, the temperature control in engineering practice is mostly limited to the temperature monitor. In this paper, MIDAS finite element analytical software was used to simulate the temperature field of mass concrete in a certain high-rise building foundation, the change rules of temperature and temperature stress with the time was calculated and analyzed by finite element analysis; at the same time, simulation result was verified by the temperature measurement data. It concludes that key to temperature control of mass concrete lies in the dual control of temperature and temperature stress. The simulation analysis of finite element procedure is feasible as an auxiliary method of temperature control and management.

Keywords: Mass concrete; Temperature field; Temperature stress; Temperature control; Finite element

1. Introduction

With the increase of high-rise and super high-rise buildings, most of the high-rise building foundations have adopted raft foundation, composite foundation of pile and raft and box foundation, most of these foundation mat are made of "mass concrete" which belongs to the concrete [1] whose structural dimension must require for related technical measures, proper settlement of internal and external temperature gap, reasonable settlement of temperature stress and control based on crack. According to the definition of mass concrete, the temperature control is of great significance in assuring the quality of mass concrete.

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2. Temperature constitution and temperature stress of mass concrete

Upon pouring molding of mass concrete, it undergoes the following changes: initial pouring temperature increases to maximum temperature and ultimately reduces to the stable temperature. The maximum temperature in the concrete is composed of three parts: pouring temperature; adiabatic temperature rise from cement hydration temperature; heat radiation temperature.

The temperature stress is caused by the temperature change (temperature difference) in the object. In case of variable temperature in various parts of the object, the deformation featuring "heat swelling and cold shrinkage" will be triggered; the deformation is limited by the mutual restriction and boundary restriction between various parts of the object and can not occur freely. The constraining force arising from these restrictions is temperature stress.

3. Simulation analysis of finite element procedure

3.1. Project Overview

A certain commercial and residential building project in Kunming has a building height of 99.15m (above the ground). The tower building is grouted by Long spiral bored piles + raft foundation , the raft foundation thickness includes 1800mm and 2700mm. Figure 1 displays plan layout of foundation and temperature measuring point.

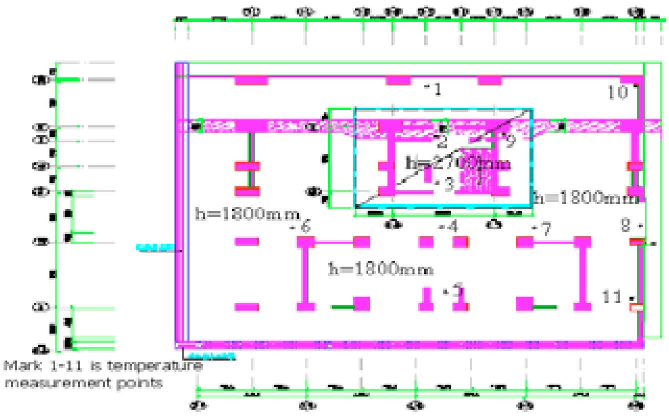


Fig .1.Plan layout of foundation

The raft foundation is designed to adopt C50 concrete with an anti-seepage level of 0.8×10^6Pa (please see Table 1 for the concrete burdening ratio). The pouring volume of single concrete block is about 1500—2000 m^3.

Table 1.Burdening ratio of C50P8 concrete

Concrete grade	Water (kg/m^3)	Cement (kg/m^3)	Fly ash (kg/m^3)	Slag powder (kg/m^3)	Mixed sand (kg/m^3)	Grave (kg/m^3)	Superplasticizer (kg/m^3)	Expansive (kg/m^3)	w/c ratio
C50P8	172	390	46.8	39	729	1041	17.55	31.2	0.361

The following temperature control measures are adopted for the project: One layer of straw mat or gunny bag immersed in water for a long time is first laid on the external surface of concrete; then two layers of dry straw mat are laid for heat insulation; the covering materials are increased or reduced according to the temperature gap; the cooling water pipe is set up in the concrete. Figure 2 is layout of cooling water pipe.

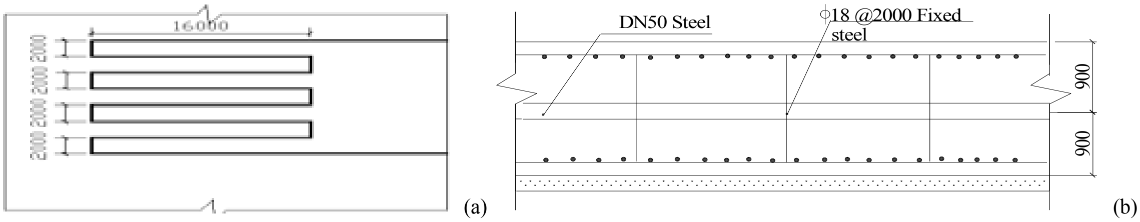


Fig .2. (a) Plan layout of cooling water pipe; (b) Vertical layout schematic of cooling water pipe

3.2. Analytical procedure of finite element procedure

The article adopts structural analysis finite element software MIDAS/Civil to implement value simulation analysis to the large-volume concrete temperature field and temperature stress. It can be divided into the following three procedures:

3.2.1. Model establishment and necessary parameter confirmation.

This process mainly includes the material features related to time such as creep, dry shrinkage and elastic modulus and setup of boundary.

3.2.2. Analysis of temperature stress process.

This process mainly includes the setup of temperature, distribution of heat source and setup of construction simulation time.

3.2.3. Result analysis.

It mainly includes the temperature change graph and temperature stress change graph.

3.3. Procedure model establishment

The mass concrete and natural foundation is selected and adopted as the calculation object for modeling; the concrete thickness is 1.8m and 2.7m; the length is 38m and width is 46m; the soil thickness is 3m, length is 42m and width is 54m. Axis Z is along the thickness direction, axis X is along the length direction and axis Y is along the width direction.

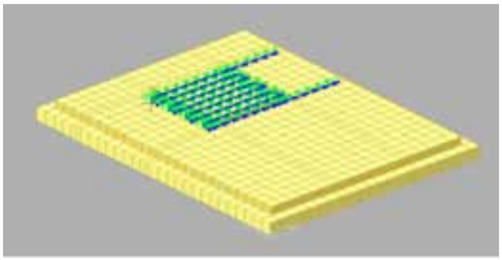


Fig .3.Finite element model added into the cooling water pipe upon grid distribution

The grid is distributed according to the concrete shape; the Mass concrete foundation (part with a thickness of 1.8m) length and width direction includes 21 units and 27 units respectively; each unit is 2m; the thickness direction is divided into 6 layers and each layer is 0.3m in thickness; the mass concrete foundation (partial part with a thickness of 2.7m) length and width direction includes 8 units and 9 units respectively; each unit is 2m; the thickness direction is divided into 3 layers and each layer is 0.3m in thickness (the top layer is further divided into three layers; each layer is 0.1m in thickness); the natural foundation thickness direction is divided into three layers; the layer is 1m in thickness; the length and width direction is 2m in each unit. Figure 3 displays the grid shape upon distribution.

3.4. The initial and boundary conditions

Environmental temperature: Average daily temperature is 21 ºC.

Initial concrete temperature: The measured model entry temperature of concrete is 23.2 ºC—26.8 ºC; in order to reflect the possible maximum temperature, 26.8 ºC is adopted for the procedure analysis.

Flowing temperature of cooling water: The measured temperature is 19—22 ºC, 21 ºC is adopted.

The concrete surface, surrounding steel model and air contact surface is treated according to Type III boundary conditions; the natural foundation and foundation contact surface is treated according to Type IV boundary conditions; the contact is good and natural foundation is simulated into a structure with certain specific heat and heat transmission rate.

The natural foundation is treated as follows: The side and lower bottom of natural foundation adopt the fixed natural foundation temperature (21ºC); the model is established for the restriction conditions according to the body unit: general support restriction conditions are adopted.

3.5. Thermal parameters of concrete foundation and natural foundation

These thermal parameters of Table 2 are obtained through on-site measurement, calculation and piling-up.

Table 2.The material and thermal characteristic parameters

Characteristic	Concrete foundation	Natural foundation
Specific heat (J/kg •k)	0.97e+3	0.92e+3
density（kg/m^3）	2500	1600
Heat conduction coefficient（w/m •k）	2.67	1.30
Convection coefficient (w/m^2· k)	4.53	4.53
Concrete compressive strength（Pa）	43.6 e+6(7d) 62e+6 (28d)	
Strength development coefficient (ACI)	a=4.0 b=0.85	
Elastic modulus of 28 days (Pa）	3.45e+10	1e+3
Thermal expansion coefficient	1e-5	1e-5
Poisson's ratio	0.2	0.3
Amount of cement per cubic（kg/m^3）	390	

3.6. Temperature and temperature stress analysis

3.6.1. Situation analysis of temperature field

Table 3 reflects the difference of values between the measured and program analysis; Figure 4 and Figure 5 display the temperature change curves of concrete, Figure 4 display program analysis result, Figure 5 display the measured result (With 9 # temperature measurement point as an example, 9 # point is the point of maximum temperature at the corner of core cylinder).

Table 3.Comparison between measured maximum temperature and procedure analytical value in the foundation concrete

The days after pouring concrete (day)	Temperature measured(℃)	Program analysis (without cooling pipe)(℃)	Program analysis (with cooling pipe) (℃)
1	66.4	68.9	68.9
2	79.2	81.1	80.3
3	82.5	84.8	83.1
4	81.9	84.1	82.5
5	81.9	81.7	80.3
6	78.5	79.1	77.6
7	74.6	76.7	75.2
8	71.3	74.3	72.1
9	69.5	72.0	70.7
10	65.9	69.9	68.6

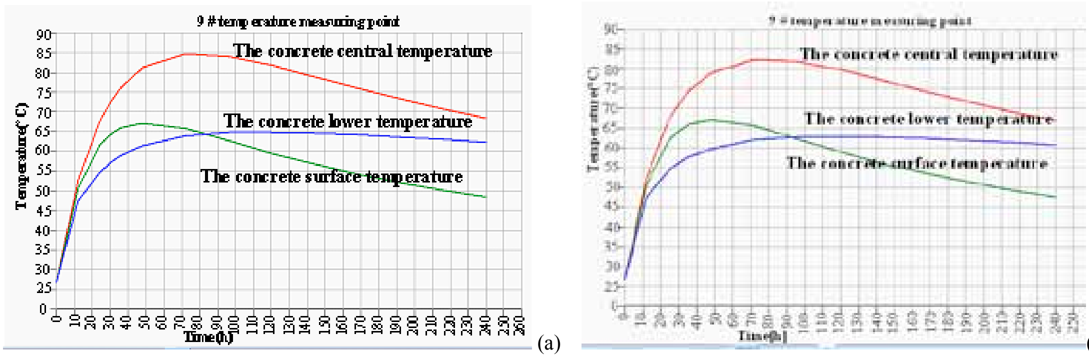


Fig. 4. (a) Temperature change curve (without cooling pipe); (b) Temperature change curve (with cooling pipe)

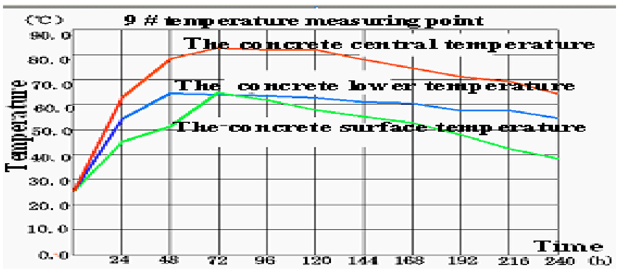
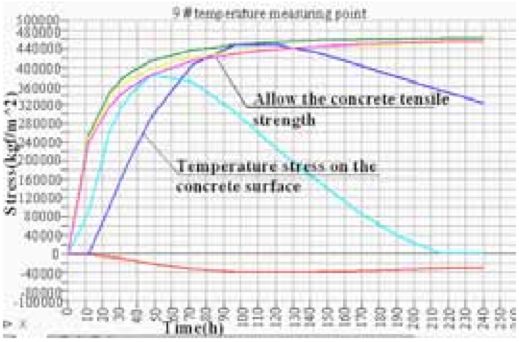


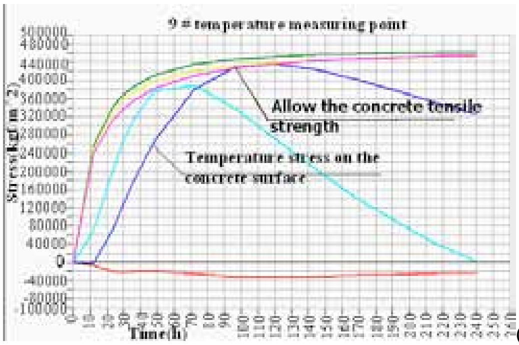
Fig. 5.Measured temperature change curve

3.6.2. Situation analysis of temperature stress

Figure 6 and Figure 7 display the change of concrete temperature stress in the different thermal insulation layer (With 9 # temperature measurement point as an example).



(a)



(b)

Fig. 6. (a) Three layers straw mat (without pipe cooling); (b) Three layers straw mat (with pipe cooling)

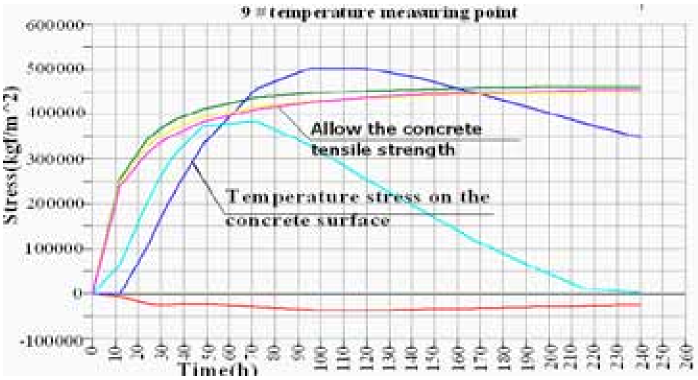


Fig. 7.Two layers straw mat (with pipe cooling)

3.6.3. Analytical result

The analysis of above temperature and temperature stress forms and graphs is as follows:

- First, it can be seen from Table3, Figure4 and Figure5 that procedure simulation analysis obtains the comparison between daily maximum temperature and measured statistics temperature in the concrete under no cooling pipe and with cooling pipe, we can conclude that procedure analysis is basically same as the measured temperature and time change tendency. As for the time and value of peak hydration heat in the middle of concrete, the procedure analysis is rather compatible with the measurement.
- Second, Figure4.(a) and Figure4.(b) display that comparison of concrete temperature with cooling pipe and without cooling pipe, we can conclude that maximum temperature in the middle of concrete has reduced to some extent upon adoption of pipe cooling measures. It can be seen from Fig4.(a) and Fig6.(a) that 9# point without cooling pipe has a temperature gap of not above 25 ºC, yet the temperature stress exceeds the allowable concrete tensile strength within 3~5 days in small margin; Fig6.(b)displays the temperature stress of 9# temperature measurement point with cooling pipe is controlled within an allowable tensile strength of concrete; besides, 9# temperature measurement point is also under cooling pipe condition (Figure 7) but heat insulation and servicing measures are changed so that temperature stress exceeds the allowable tensile strength of concrete. The above phenomenon has reflected two points:

the pipe cooling measures are effective yet pipe cooling measures are coordinated with the preserve temperature and maintenance method; it is inadequate to observe the temperature control of mass concrete, it has to integrate with the temperature stress for integrated analysis.

4. Three proposals for temperature control of large-volume concrete

4.1. The formula for adiabatic temperature rise of concrete

At present，the hydration heat of mass concrete finite element analysis and planning construction scheme in engineering practice, there are the adiabatic temperature rise calculation and data entry, current general formula (1) need to be amended.

$$T(t)=WQ\,(1-e^{-mt})/c\rho \tag{1}$$

The formula (1), “W” means cement content, “Q” means the total heat of hydration of cement, “m” means heating rate, “c” means specific heat of concrete, “ρ” means concrete density concrete.

About "Q" values, engineering practice, with a strength grade of cement for different manufacturers, different batches of the same manufacturer will have a big difference, not a constant, it is recommended by the experimental data of 3d and 7d of the cement hydration heat to calculate the total heat of hydration is better. About cementing materials "W" value, "W" is not only that the amount of cement，project should be based on actual amount of the mineral admixture. The cementing material "W" value is: W = Cement + Expanding agent + K (Fly ash +Slag powder), by trial, K values are 0.3. About heating rate "m", the value of "m" in the project should contact the specific varieties of cement, cement, admixture, etc. The value of documentary [2] is: m=0.43+0.0018Wcement，the value of documentary [3] is 0.7～1.1. In this paper, this value of 1.05 is obtained by trial.

4.2. About the limit value of temperature

At present, the engineering is widely considered the mass concrete temperature control of the temperature difference between inside and outside control is less than 25 ℃; however, the concrete temperature difference in some time period of the project cases exceeds 25 ºC without cracking. Some projects such as documentary [4] has mentioned that internal surface temperature difference of concrete in “raft foundation project of Century Wealth Centre” is 35 ºC without cracking; documentary [2] maintains the following temperature control conditions for industrial, civil and building large-volume concrete: the internal surface temperature gap is controlled within 30 ºC. From my viewpoint, temperature control and management of mass concrete in the actual project through such temperature control index is rather rough. As documentary [5] has mentioned that R.Springenschmid and others from the Institute of Building Materials in Munich University have recommended using “crack temperature” (crack test frame) for control for the purpose of testing “crack temperature” parameter of various concrete products and selecting or regulating the materials and burdening ratio of concrete. From my viewpoint, similar test can be implemented according to the concrete burdening ratio, material and servicing conditions of various projects before construction of large-volume concrete, especially important projects (the test implemented by temperature—stress tester developed by the research institute of building materials in Tsinghua University is a very good attempt); at the same time, it has to integrate with the computer simulation and find out temperature control index in accordance with the concrete project conditions.

4.3. The temperature stress control

At present, numerous project monitor reports only belong to a temperature measurement report and can not totally reflect the actual project. From my viewpoint, we can implement computer simulation and analysis and find out weak stress points, then pre-embed strain test elements in the construction; convert the measured strain value into stress value, then know the stress change of pouring block in a timely manner, implement contrast analysis with concrete strength in order to make a timely regulation to the construction plan, adopt related technical measures with aimed purpose and realize dual control of “temperature” and “temperature stress” in the real sense.

5. Conclusion

Control of “temperature” and “temperature stress” is the key point of prevent cracks of mass concrete. At present, the temperature control parameters have certain changes, the current specifications are imperfect and temperature control in the actual project is limited to temperature control. The simulation analysis of finite element procedure can realize the organic integration between modernized technical measures and actual project; it can realize dual control of temperature and temperature stress; it is feasible as an auxiliary method of temperature control and management and enjoys wide application in the actual project.

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