CHEMICAL ENGINEERING TRANSACTIONS
VOL. 66, 2018

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Songying Zhao, Yougang Sun, Ye Zhou

ISBN 978-88-95608-63-1; **ISSN** 2283-9216
DOI: 10.3303/CET1866198

Study on Hydration Heat Coefficient of Mass Concrete Construction

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This paper aims to prevent and control the hydration heat crack by analyzing the hydration heat coefficient in a bridge construction project, in which process it explores the reasons and concrete parameters as well as takes corresponding control measures. The analysis suggests that the reason for the hydration heat phenomenon in this project lies in temperature change. And the conclusion is that the calculation precision of the analysis fitted by cubic polynomials is higher than that of traditional analysis fitted by quadratic polynomials, so that the hydration heat phenomenon can be dealt with in a better way.

1. Introduction

At the initial stage of the hardening of concrete, the water spray effect between cement and waterborne raw materials releases relatively a large amount of heat that increases the overall temperature of the concrete, which is called hydration heat phenomenon and is common in many kinds of concrete structures. In normal size concrete structures, due to the high heat dissipation condition, the internal and external temperature difference of concrete in hydration heat process doesn't change too much and serious engineering cracks rarely occur. However, in the mass concrete structures in modern construction projects, its heat dissipation condition is limited due to its large mass so that the heat cannot be dissipated rapidly and the internal and external temperature difference of concrete tends to be a big one, which may lead to the creation of harmful cracks.

Since the scale of modern concrete construction projects is on the rise, the hydration heat phenomenon has to be controlled. Therefore, this paper based on previous studies, analyzes a large bulk road and bridge construction project in the aspects of temperature field, temperature stress, and coefficient of hydration heat of concrete, and provides corresponding suggestions on hydration heat temperature control and crack prevention.

2. Literature review

The research on temperature field and temperature stress of mass concrete structure started at the building of the Hoover dam with high 221m in the United States in the mid-1930s. At that time, the United States Bureau of reclamation organized the new construction technology research, such as water pipe cooling, low temperature air cooling and assembly precast blocks, and achieved satisfactory results. Many of the mass concrete technologies adopted by Hoover dam are still in use.

Since 1940s, many countries, such as the United States Bureau of reclamation, the former Soviet Institute of water engineering and the scholar Alzyoud, have made a thorough study of the actual design, construction technology, temperature control index and temperature control measures of the mass concrete structure, such as the laminated block of the pouring block. The proper reduction of cement content, Low thermal cement, various aggregate precooling methods, and calculation of temperature field and temperature stress are selected. The emphasis is on the prevention of cracks in the mass concrete structure, and various technical measures for effective treatment of the existing cracks are also explored (Alzyoud et al., 2016).

The Fifteenth International dam conference held in 1985 listed concrete cracks as one of the four topics of the conference. In 1992 at the third RCC conference in Santiago, California, Batog and Giergiczny creatively introduced the classic concrete dispersion crack model into the analysis of dam thermal stress (Batog and

Giergiczny, 2017), the scholars Frenzel and Curbach first calculate the temperature field of the dam by the finite element method and the difference method, and use the ADINA program to calculate the three-dimensional stress field, and predict the possibility of the cracking of the palace otter dam during the construction period and the operation period (Frenzel and Curbach, 2017).

After 1950s, a lot of work has been done on the research of the temperature field and the temperature stress of the mass concrete structure, and great achievements have been made. In early 50s, two arch dams of Fuzi ridge and Meishan were built in the middle reaches of Huaihe. The longitudinal slot of the Fuzi ridge dam is set up in the piers, and then backfilled with concrete. There are basically no cracks in the piers, but there are more cracks in the arch. In the design of Meishan multi arch dam, there are contraction joints in the arch, and there are not many cracks after completion. China has attached great importance to the numerical analysis and theoretical study of the temperature stress of the mass concrete structure. In 1973, the academician Zhu Bofang of China Institute of water conservancy and Hydroelectric Science and technology developed the first finite element program of the temperature creep stress of the concrete in China and applied it to the analysis of the temperature stress in the bottom hole of Sanmenxia. At the end of 70s, Tongji University, Hohai University and Tsinghua University carried out corresponding research and application.

Scholar Ghasemzadeh and others completed the 2D and 3D finite element simulation program system of the large concrete structure from 1990 to 1992 combined with the Xiaolangdi Dam project (Ghasemzadeh et al., 2016). Scholars Haar and Marx use the artificial short joints to solve the problem of temperature tensile stress on both sides of the RCC arch dam, and the simulation of pipe cooling is easy to handle. They also consider the environmental factors and the randomness of the thermodynamic parameters of concrete, and give the random variational principle and the random finite element formula which can reflect the randomness of the material parameters (Haar and Marx, 2017).

Since the end of the last century, many colleges and universities have carried out the research on the temperature stress of mass concrete structures. The calculation of the temperature stress of large volume concrete, such as Longtan, Xiaowan, Xiluodu and TGP, has been carried out and valuable results have been obtained.

In 1950s, the economic and technical level of our country was low, and the large volume concrete was only in a few key projects such as large dams, and it was rarely encountered in small and medium sized projects. However, from the late 70s, especially in the 90s, large industrial buildings, public buildings, high rise high-rise civil buildings flourished, and more and more large volume reinforced concrete engineering. In recent years, domestic and foreign scholars have done a lot of experimental, theoretical and numerical analysis on the temperature problem. The research on temperature field and temperature stress of mass concrete structure in China is more comprehensive and thorough and has reached a higher level. The calculation of the temperature field and the temperature stress is developed from the two-dimensional finite element model to the three-dimensional finite element model, and the technical level of the numerical analysis method has been greatly improved.

In the field of civil engineering, Professor Wang Tiemeng of China Metallurgical Building Research Institute has been devoted to the study of cracks in civil engineering structures. Professor Wang Tiemeng has been engaged in the research of mass concrete in 50s. For many years, Klemczak and others have carried out field scientific experiments and theoretical research in combination with engineering practice and have solved a great number of technical problems for national key construction (Klemczak et al, 2017). Scholar Saeed and others put forward the basic formula for the concrete structure to bear the continuous restrained temperature shrinkage stress, and accordingly formed a set of comprehensive control theory and approximate calculation method of “anti” and “put”. By using the comprehensive research method, the design principles of “anti” and “put” are put forward, and the technical viewpoints of two design schools with slit and no slit are unified, and the calculation formulas of expansion joint and crack control are put forward in combination with practice (Saeed et al., 2015). Zhu and other scholars have developed a set of three-dimensional finite element temperature analysis program package 3D-TEEP, which can simulate the actual construction process of concrete, considering complex factors such as the concrete layered casting, pouring layer thickness, pouring temperature, construction intermittence, concrete hydration heat divergence law, maintenance mode, external temperature change, concrete and foundation elasticity, modulus change and creep (Zhu et al., 2016).

To sum up, the above research work mainly studies the theoretical research on the temperature cracks in the mass concrete structure to improve the crack resistance design theory of large volume concrete. Starting from the actual problem of mass concrete, the internal temperature of concrete increases rapidly because of the concrete hydration and exothermic during the early hydration process. For large volume concrete, the appearance of temperature difference in the inner surface is accompanied by the emergence of the temperature stress, and the early temperature stress is very considerable, so the concrete surface is pulled. If the tensile stress exceeds the tensile stress of the surface concrete, it will have a negative effect on the stability of the structure. Therefore, based on the above research status, this paper makes a comprehensive analysis of the temperature stress related problems of the civil structure based on the study of the temperature field and the temperature stress of the predecessors.

3. Research method

3.1 Layout of monitoring scheme of hydration heat temperature sensor

In order to analyze the temperature field and stress of the specific bridge construction project, a temperature sensor is installed for detection in the construction site. In the installing process: the size of the 15# pier bearing platform is 19.2m×13m×4m; the strength degree of the concrete is C40; the amount of different kinds of materials in per cubic meter concrete is: 291kg P.42.6 (low alkali) cement, 750kg sand, 1080kg granite, 125kg admixture (fly ash), 4.16kg water reducing agent, and 154kg water; during the construction, pour concrete into the steel framework, and prearrange two layers of cooling water pipes which is made of DN50 (2 inch) galvanized steel; the horizontal and the vertical spacing of cooling water pipes is 2 m respectively, and the overall circulating water supply (only one inlet and outlet) is adopted. The installation of the temperature monitoring point area mainly aims to reflect the internal and external temperature difference, cooling speed and environmental temperature of mass concrete blocks. As the 15# pier bearing platform has a symmetrical structure, the number of sensors can be reduced, and only a few representative points are needed. There are six temperature monitoring points installed, and the position of the sensor is shown in Figure 1, in which measuring point 1 is located at 1m above the center of the bottom surface of the bearing platform; point 2 is located at the center of the dark side of the bearing platform; point 3 is at the center of the bearing body; point 4 and 5 are located at the up and down 1/4 points of the diagonal of the bearing body respectively; point 6 is located near the cooling water pipes.

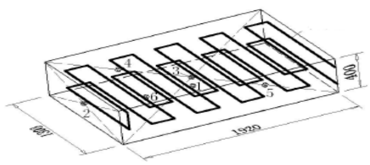

Figure 1: The schematic layout of the sensor (cm)

The temperature sensor adopted by the temperature monitoring is AD592 integrated temperature sensor, which has high measurement accuracy and its measurement range is -25~105□ (the error is less than + / - 0.1 □); Each sensor has a unique ID number to facilitate data collection and recording. The temperature readout adopts LTM8261 handheld multipoint temperature tester, which can provide power for battery, and test and code the sensor without computer, indicating that it’s suitable for the application in occasions without computer, as shown in Figure 2. To ensure that the temperature sensor is not damaged during concrete pouring, it is installed on the lower edge of the steel bar or angle steel and an insulating tape is placed between the temperature sensor and the steel bar. In order to facilitate the temperature monitoring work, the leads of the temperature sensor are stretched out the bearing platform uniformly, and data collection is carried out at appropriate positions. During 329 h after concrete pouring of 15# pier bearing platform, this paper measures the temperature of each measuring point, and the data has been recorded. Due to severe change of the hydration heat temperature in the initial stage of concrete pouring, the initial interval for data collection is 2 h, and it is adjusted as 4 h after the change tends to be slow, finally it is adjusted as 10 h the temperature becomes stable.

Figure 2: The temperature sensor and handheld temperature readout

3.2 Field measurement and data analysis

Concrete pouring of 15# pier bearing platform began at 11 a.m. on August 18, 2011, and the molding temperature is 32.3 □. When the concrete was poured to 3.2 meters from the bottom of the bearing platform, the cooling water pipe began to enter the water. The pouring was completed at 8 a.m. on August 20, and the cooling pipes stopped water supply at 11 a.m. the next day. The concrete steel formwork on the bearing platform was removed at 2 p.m. on August, 22. According to the temperature monitoring scheme, the monitoring data of hydration heat temperature of 15# pier bearing platform were collected and recorded, but it is not elaborated here due to the limitation of space.
First of all, in order to facilitate the analysis of hydration heat temperature changes at each measuring point, the temperature data of all measuring points measured and collected in the field during 329 h after the concrete pouring of 15# pier bearing platform were plotted into a temperature curve. Measuring point 1 is located 1m above the center of the bottom of the bearing platform. Starting counting when the concrete is poured at point 1, the temperature curve is shown in Figure3.

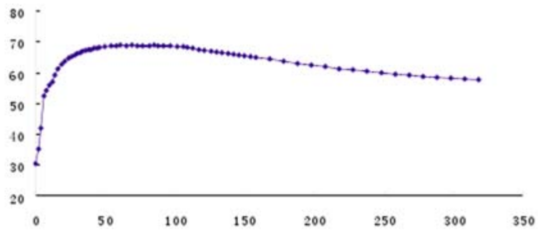

Figure 3: The hydration heat temperature curve of measuring point 1

From Figure 3, it can be seen that within 16 h, the temperature of the concrete at measuring point 1 rose sharply, reaching 80% of the highest temperature; and then the temperature rise trend slowed down. In the 61 h after molding, the temperature of the concrete at measuring point reached 68.9 □, the highest temperature, and the temperature lasted until 90 h. Then it began to slow down and tended to be stable. In the 318 h after molding, the concrete temperature of point 1 dropped to 54.2 □, compared with the highest temperature, decreased by 21%. Therefore, the maximum temperature rise of concrete at point 1 was 38.5 □, and the average cooling rate was 1.37 □ / d, which met the requirements of the 3.0.4 term in Mass Concrete Construction Specifications (GB50496--2009): the cooling rate of concrete pouring body should not be greater than 2.0 □ / d.
Secondly, the temperature curve of hydration heat at measuring point 2 was analyzed. Measuring point 2 is located at the center of the dark side of the bearing platform. Starting counting when the concrete is poured at point 2, the temperature curve is shown in Figure 4.

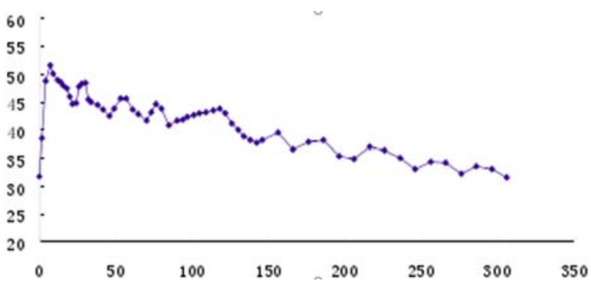

Figure 4: The hydration heat temperature curve of measuring point 2

According to the figure, it can be seen that in the 10 h after molding, the temperature of the concrete reached the highest 51.6□, and then it began to decrease. In the 306 h, the temperature dropped to 31.5□, which is consistent with the temperature of the surrounding atmosphere. The maximum temperature rise of concrete at point 2 was 19.9□, and the average cooling rate was 1.63 □ / d, which met the requirements of the regulation. Since measuring point 2 is located at the center of the dark side of the bearing platform, which was influenced greatly by the external environment, so that the temperature at this point fluctuated with the ambient temperature, but the overall temperature changing tendency was dropping after reaching the highest temperature, and the final temperature change tends to be moderate. Under the influence of night cooling and air convection, the temperature at measuring point 2 was significantly lower than that at other measuring points.

3.3 Numerical simulation analysis

When the value of thermal performance parameters of concrete has not been obtained, it can be estimated according to the weight percentage of each component of concrete. According to the mix proportion of concrete of 15# pier bearing platform, the amount of each component of per cubic meter C40 adopted is as follows: 291 kg cement, 750 kg sand, 1080 kg granite, and 154 kg water. Table 1 shows the heat conductivity coefficient and the specific heat of each component.

Table 1: The heat conductivity coefficient and specific heat of main component

Constituent components	Thermal conductivity	specific heat
water	2.160	4.187
Ordinary cement	4.593	0.536
Quartz sand	11.099	0.745
Granite	10.467	0.708

4. Results and discussion

4.1 Modeling

The entity units in finite element analysis software MIDAS/Civil 2010 are adopted for modeling, which can be used for thermal analysis of 3d steady state or transient state. The model has 17431 nodes and 14848 entity units. According to the actual layout of cooling water pipes in the construction site, there are 2 layers of cooling water pipes in the calculation model of 15# pier bearing platform, the horizontal and vertical spacing of which is 2 m. The concrete hydration heat temperature in the 320 h after modeling at each measuring point can be calculated. In order to facilitate the analysis, the concrete hydration heat temperatures calculated at each measuring point are plotted into a temperature curve, as shown in Figure 5.

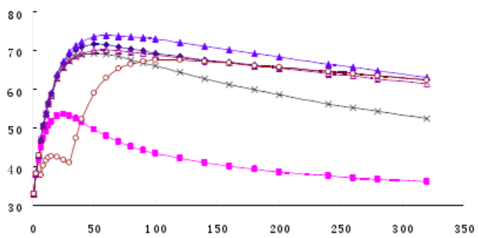

Figure 5: The calculated hydration heat temperature curve of each measuring point

The calculated results show that the variation trend of hydration heat temperature at each measuring point is basically the same: the initial temperature rise rate is relatively fast, and the maximum temperature is reached around 50h after the concrete is poured into the mold, and then the temperature begins to decrease. As can be seen from Figure 5, influenced by cooling water, the rise speed of concrete temperature slows down, and the temperature of concrete near the cooling water pipe drops sharply. After the cooling system is closed, the dropping trend of concrete temperature at each measuring point of the bearing platform slows down. Influenced by environment temperature and air convection, the temperature decline of measuring points on surface is relatively obvious, which is 15 □ lower than that of other measuring points at the same time.

4.2 Contrastive analysis of measured data and calculated results

In order to verify whether calculated temperature is consistent with the measured temperature on site, the calculated values at each measuring point are compared with the measured ones. In addition to the values at point 2, other measured values are roughly consistent with the calculated temperature curve, among which the temperature curve calculated by MIDAS/Civil 2010 is smoother than the measured one since many influencing factors in actual situation are ignored in the finite element analysis. The calculated values at point 1 are in good agreement with the values obtained from the actual measurement: the calculated temperature curve reaches the maximum temperature at 63h, and the measured temperature curve reaches the at 72h. The actual measured temperature at point 2 is entirely 10 ℃ lower than the corresponding calculated temperature;

Although the general trend of the two values is downward, the falling trend of the measured curve is more similar to the change of atmospheric temperature. This shows that in the actual situation, the surrounding environment has a great influence on the hydration heat temperature of concrete.

5. Conclusion

In this study, it is found that the temperatures of the measuring points on the same section of 15# pier bearing body in the example project are distributed in a symmetric parabola along the pier wall thickness, therefore the method fitted by quadratic polynomial is adopted and the calculation formula of temperature distribution is achieved. Comparing the calculated and measured values by quadratic polynomial, it is found that the maximum calculation error is 13%, which is reasonable. Finally the measured temperature values along the thickness of 15# pier bearing body are fitted by cubic polynomial, during which process the maximum calculation error is 6.6%, an obvious higher accuracy than the results of formula fitted by quadratic polynomial. The results show that at measuring point 1, the calculated curve is in good agreement with the measured one, and the calculated curve reaches the maximum temperature at 63h. The actual measured temperature at point 2 is entirely 10 □ lower than the corresponding calculated temperature; Although the general trend of the two values is downward, the falling trend of the measured curve is more similar to the change of atmospheric temperature.

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