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Study on the Hydration Heat Temperature Field of Large-Scale Prestressed Concrete Box Girder

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Abstract:-According to the characteristics of a long-span concrete box girder bridge, the determination of concrete parameters and boundary conditions in the numerical simulation process of hydrated heat temperature field were introduced and analyzed in detail. In this type of bridge structure, the construction of the box girder has a very important role in the project. The characteristic of the box girder is a complicated structure, which has a large volume of hydration heat on concrete during the construction process. This has a great influence on the safety, because cement will release a lot of heat in the process of hydration, internal temperature will rise rapidly over a period of time, at this temperature the difference between the internal and external temperature will attend a certain value which may lead concrete surface cracks, thereby affecting the safety of the project. In this paper, a special bridge in Anhui Province is used as the engineering case study. By establishing a finite model, the temperature distribution of the zero blocks in the hydration heat was analyzed, and the temperature effect of the prestressed continuous box girder bridge at different temperature was analyzed. The results showed that the temperature increase in the first stage to reach a maximum temperature pink after is come down in the second stage. For the hierarchical placement, the web of the old concrete crossbeam junction is prone to crack. Therefore, strengthening the conservation properties of the bridge temperature of steel and other condition to improve the mechanical properties of concrete should be taken into consideration.

Keywords: *-PC box girder, bridge engineering, hydration heat, temperature field, numerical simulation*

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I. INTRODUCTION

During the procedure of setting and hardening in concrete, the temperature profile displays a gradual nonlinear distribution due to the evolution of the hydration in cement. When Portland cement is mixed with water, warmth is liberated. This warmth is called the heat hydration, the result of the exothermic element reaction between cement and water. The heat produced by the cement`s hydration increases the temperature of concrete. For the period of concrete building, the warmth is dissipated into the soil or air and causing temperature variation inside the construction are not important. But in certain circumstances, mainly in huge constructions, such as dams, mat foundations, or some section more than one meter or yard thick, the warmth cannot be readily released. The mass concrete can then reach great inside temperature, particularly throughout hot weather construction[1].

Prestressed concrete is unique of the most reliable, durable, and extensively used construction materials in constructions, and bridge projects around the world. It has made significant influences to the construction manufacturing, the precast manufacturing industry, and the cement industry such as a whole. It has led to an enormous array of structural applications, including buildings, bridges, nuclear power vessels, and offshore drilling platforms [2-4].

The prestressed concrete of a box girder is large in volume, measured in unit per volume of concrete, and obviously has mass volume characteristics. After a great quantity of hydration heat is produced, the heat doesn't emit in a short time because the temperature difference between the inside and outside of the construction is excessively large which causes large temperature stress to make the concrete flaw[5-7]. The cracks caused by thermal stress have characteristics of wide cracks. The existence of cracks will have an adverse effect on the bearing capacity and durability of structures. In recent years, the study of the thermal analysis of box-girder bridge becoming important and experience has been accumulated [8-11]. Few types of research have focused on single box single room, single box two rooms, and single box three rooms, which are high significance to an ultra-wide section box girder. A special bridge in Qing Yijiang is a prestressed concrete continuous box girder bridge of curved four-line high-speed passenger lane. Based on the analysis of Qing Yijiang bridge single box three rooms continuous beam zero blocks. During the manufacture of the project, the hydration field heat information was collected. In this paper, comparison of collected field data and numerical simulation using ANSYS software is presented

II. TEMPERATURE FIELD CALCULATION PRINCIPLE

A. *Establishment of Heat Conduction*

After pouring concrete, heat generated in the cement under the action of water can be regarded as an internal heat source which is a uniform continuous medium transient temperature field. Assuming that the concrete continuous, homogeneous, isotropic, the casting, heat conduction equation can be expressed as:

$$\alpha\left(\frac{\partial^2 T}{\partial X^2}+\frac{\partial^2 T}{\partial Y^2}+\frac{\partial^2 T}{\partial Z^2}\right)+\frac{Q}{c\rho}=\frac{\partial T}{\partial \tau}(1)$$

In the formula, α (J·h-1·°C-1) is the thermal conductivity, T (°C) is the instantaneous temperature of the concrete, Q [Kcal/m3] is the heat source density, c [Kcal/ (kg·°C)] is the concrete specific heat, and ρ (kN/m3) is the concrete density.

Because of the hydration heat under the adiabatic condition, the temperature rise of the concrete is given as:

$$\frac{\partial \theta}{\partial \tau}=\frac{Q}{c\rho}=\frac{W_q}{c\rho}(2)$$

In the formula θ (°C) is the adiabatic temperature rise of concrete, W (kg/m3) is the amount of cement, and is the quantity of heat emitted by a unit mass of cement per unit time. So the equation of heat conduction can be rewritten as:

$$\alpha\left(\frac{\partial^2 T}{\partial X^2}+\frac{\partial^2 T}{\partial Y^2}+\frac{\partial^2 T}{\partial Z^2}\right)+\frac{\partial \theta}{\partial \tau}=\frac{\partial T}{\partial \tau}(3)$$

In the formula, the heat source strength Q (Kcal/m3) can be obtained by the formula of dependent accumulated heat.

B. *Determination of boundary conditions*

The heat conduction equation for temperature and time of the objects are established. In order to determine the relationship between the half space temperature required the need to know the initial and boundary conditions are required. The boundary conditions forth interactions between the concrete surface and the surrounding medium.

There are 4 types of boundary conditions, in this paper, due to external and internal air the convection heat exchange boundary belongs to the third boundary conditions given:

$$-\lambda\frac{\partial T}{\partial \eta}=\beta(T-T_{\alpha})(4)$$

In equation (4), ß is the surface heat release coefficient. The third kind of boundary condition represents the heat transfer condition between the solid and the fluid (such as air).

III. DETERMINATION OF PARAMETERS AND BOUNDARY CONDITION

A. *Hydration heat of cement*

In calculating temperature field for concrete structures, the basic use of concrete adiabatic temperature rises θ is required. According to the specific heat of concrete, hydration heat and adiabatic temperature rise, the bulk density and the amount of cement is calculated accordingly to 1.518*10 KJ/m3, the hydration heat formula by CHRISTIAN Cristovary[12], on the basis of the principle the chemical reaction kinetics is illustrated in equation (5) the function shown describes the concrete accumulation regulation:

$$Q(\tau)=Q_0 e^{\{-55[0.962e^{(0.039T)\tau}]-1.25\}}(5)$$

In the formula, τ (h/d) is the age, and T (°C) is the initial temperature when the concrete is poured

B. Thermal properties of concrete

In this paper, the thermal conductivity which varies with the development of hydration heat is not defined according to the temperature coefficient (6):

$$\alpha=\frac{\lambda}{c\rho}(6)$$

According to the percentage of each component of the concrete used in the field, the specific heat capacity of concrete c is 0.98 kJ/ (kg. °C) and the thermal conductivity λ is 10.1 kJ/ (m. h. °C) by using the method described in the equation (6).

C. Boundary condition

In the process of pouring the box girder, the boundary condition is divided into 2. Firstly, the concrete is in contact with direct air and secondly, the concrete surface is insulated with a thermal layer, to determine the heat transfer coefficient and the atmospheric temperature of the structure's surface.

1) Heat transfer coefficient of structural surface

The inner and outer surface of the box girder is divided into 4 categories namely: no wood template outer surface, the outer surface of the wooden template, with the inner surface of the open cavity and the inner surface of the no opening cavity. The change of wind speed is random but also has certain regularity. The wind speed considered in this paper is the average daily wind speed which is 2m/s whereas for the inner cavity surface without opening is given as 1m/s and 0m/s respectively. In recent years, many scholars have carried out research on concrete surface and air convection heat transfer coefficient[13-16], based on experimental or theoretical deduction. The formula is given different convective heat transfer coefficient value to literature; however, analysis has been carried, to fit out concrete structure surface convection on the average heat transfer coefficient formula:

$$\hbar c = 0.035\mathrm{v}^2 + 3 \cdot 62\mathrm{v} + 4.75 \qquad (7)$$

In equation (7) v (m/s) is the no opening. When a wooden formwork is attached to the concrete surface, the heat transfer coefficient, including the influence of wind speed, is given[14], as shown in the equation:

$$\begin{cases} \hbar a = 6.89 + 1.66\mathrm{v}, 1\mathrm{cm\ thick} \\ \hbar a = 4.30 + 0.41\mathrm{v}, 2\mathrm{cm\ thick} \end{cases} (8)$$

In equation (8), the v is the wind speed.

2) Atmospheric temperature

Due to lack of field data, the general use presented in [15]which are based on temperature time history simulation of diurnal change of temperature which is the local meteorological data query to the bridge located at the same time. The history of the average daily maximum temperature and average daily minimum temperature, the diurnal variation of atmospheric temperature is one times curve as shown in Figure 1. To obtain this curve the equation (9) is used:

$$\mathrm{TA(t)} = \begin{cases} (\mathrm{T_{A_{max}}} + \mathrm{T_{A_{min}}})/2 + \left[\dfrac{(\mathrm{T_{A_{max}}} - \mathrm{T_{A_{min}}})}{2}\right]\sin[((t+30)\pi)/24] & 0 \le t < 6 \\ (\mathrm{T_{A_{max}}} + \mathrm{T_{A_{min}}})/2 + \left[\dfrac{(\mathrm{T_{A_{max}}} - \mathrm{T_{A_{min}}})}{2}\right]\sin[((t-10)\pi)/16] & 6 \le t < 14 \\ (\mathrm{T_{A_{max}}} + \mathrm{T_{A_{min}}})/2 + \left[\dfrac{(\mathrm{T_{A_{max}}} - \mathrm{T_{A_{min}}})}{2}\right]\sin[((3t-22)\pi)/40] & 14 \le t < 24 \end{cases} (9)$$

With $\mathrm{T_{A_{max}}}$ is 38 °C and $\mathrm{T_{A_{min}}}$ is 28°C.

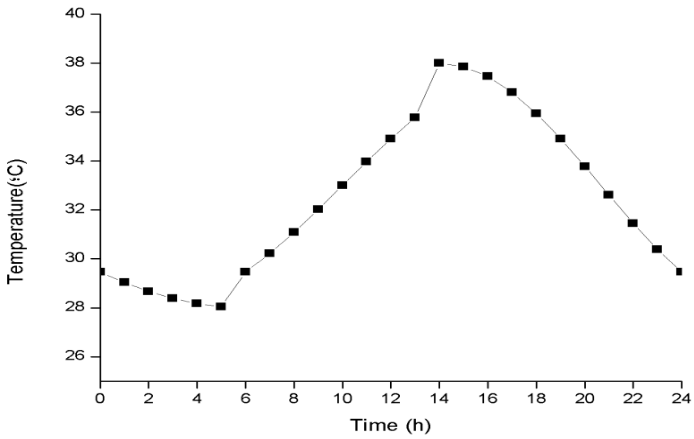


Fig 1: Atmospheric temperature change

IV. ENGINEERING EXAMPLE

A. Engineering survey

Qin Yijiang bridge (72+136+72) m is a four-line Passenger lane prestressed concrete continuous bridge, located in Wuhu, Anhui province, Full-length 281.4m, line spacing (4.6+6+4.6) m. The upper structure uses the continuous beam as the main bearing member. The main beam is showing in fig2, the top width is 22.8m, and the bottom width is 16.5m.

The Section of the single box, three straight webs, and the roof thickness is given as 55cm, 45cm, 45cm, 75cm, 95cm, web plate thickness, a thickness of 3.4m of the diaphragm in the zero blocks, plate thickness is a curve with a change rate of 50cm-155cm. Section beam height was: 5.5m from the end support of the gradient to 11m. The whole bridge is divided into 59 stages, A0 section 2, 28m long; side span 2, long 3.7m; side and central span closure section 3, long 2m; symmetric segment 13: A1-A13, B1-B13, the length is 1x3+4 x 3.5+4 x 4+4 x 4.5m.

Yijiang bridge angle is 82 degrees and currently in a navigation state. The main girder basket is asymmetrical cantilever, where pier 76# zero blocks are taken as the research object, the zero blocks are divided into two layers, the first layer is 8.25m pouring, pouring into the second layer 2.75m. The overall arrangement is shown in figure 3.

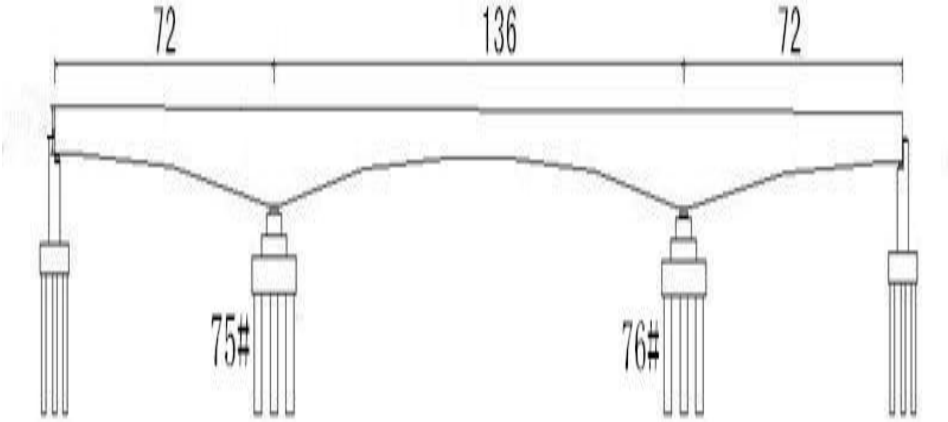


Fig 2: The general arrangement of the main bridge (unit: m)

Yijiang green bridge pouring concrete is C55 high strength concrete. In order to reduce the hydration heat of concrete, the use of fly ash is used as an admixture in the slag. Concrete adiabatic temperature rise tester is carried out for the concrete samples based on the test results, selection for the adiabatic temperature rise of the smallest group for the construction mix is considered with each concrete material dosage given as 365kg (cement), 769kg (sand), 1073kg (granulate), 115KG (water), 5.92kg (admixture (fly ash), 54kg), 74kg (powder).

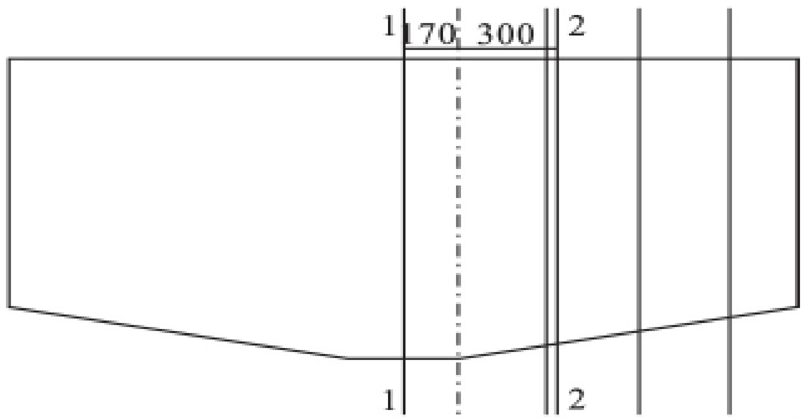
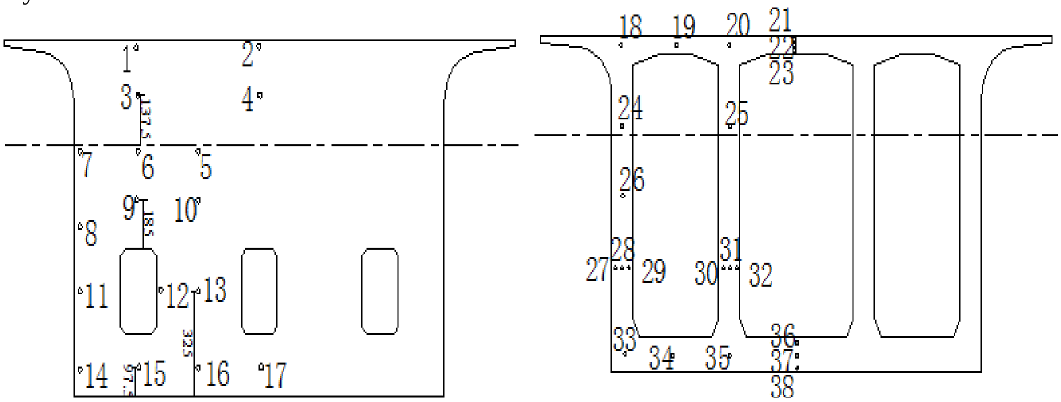


Fig 3: Sectional layout of temperature measuring points of block No. 0 (unit: cm)

B. Temperature measuring point arrangement

In order to achieve a better distribution of temperature in the zero blocks, two sections are considered namely Section 1 and section 2 arranges the temperature measurement points, as shown in Figure 4. Surface measuring point distance from the concrete surface is 5cm, a total of 38 points which is the layout of the specific points. After pouring concrete in the zero block data collection is carried, the results are obtained from the

SZZX-ZHX intelligent meter collection of temperature, whereas the ambient temperature is collected using an ordinary thermometer. The first 4 days every 2 hours a day, 5-10 days measured once every 8 hours, after 16 days every 12 hours.



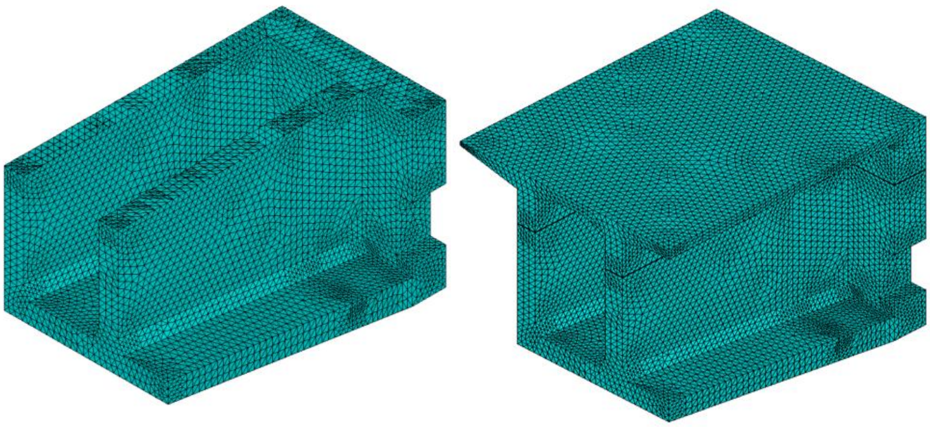
a. Section 1 of temperature measuring points b. Section 2 of temperature measuring points

Fig4: Layout of temperature measuring points (unit: cm/ the line in this layout is represented the separated line between the first and second layer)

V. NUMERICAL SIMULATION ENGINEERING EXAMPLE

A. Model building

The symmetry of zero block box beams is established in ANSYS, the model is divided into two layers: the first layer of zero blocks and the second layer of the zero blocks as shown in fig5. The model is divided into grids by using the method of meshing, and then the hydration thermal analysis is carried out in ANSYS. The two sections are symmetrical constrained.



a. First layer of zero blocks b. Second layer of zero blocks

Fig 5: Analysis model

B. Determining model parameters

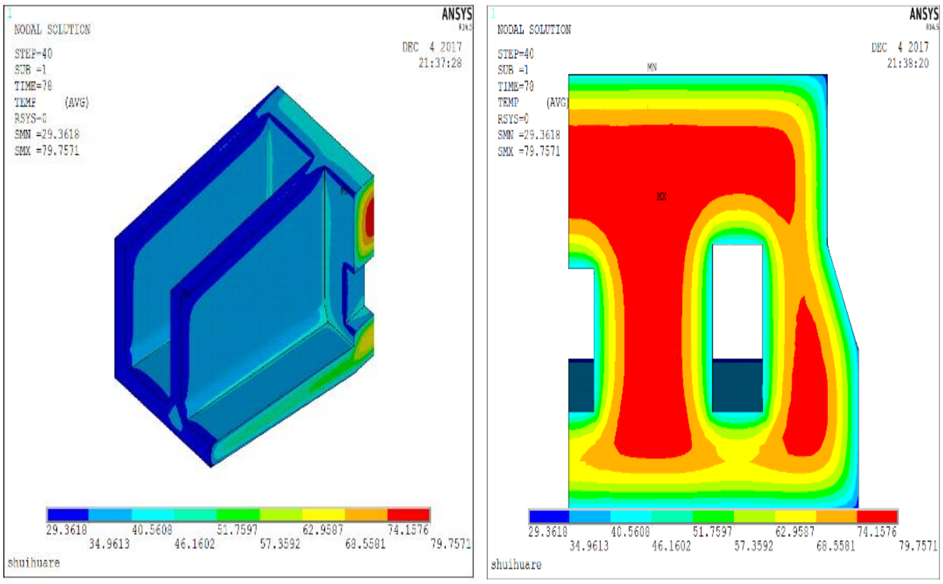
Zero blocks are placed in the summer. According to field measurements and local historical meteorological data, the average t atmospheric temperature is 32 degrees, and the template is made of steel formwork. The insulation effect of the concrete is not obvious and cannot be neglected because the block number is divided into two layers, the internal layer not the same as the external layer but the convection coefficient is the same. The Concrete pouring temperature is 29°C based on field data, in addition to this the parameters for the actual condition for the project is illustrated in Table.

Thermal conductivity (Kcal/(m· h · °C))	Specific heat(Kcal/(kg · °C))	Convection coefficient (Kcal/(m2· h · °C))	Poisson's ratio	Compressive strength (MPA)	Elastic Modulus(KN/m 2)
2．17	0．21	9．55	0．2	37	3．6 × 10 7

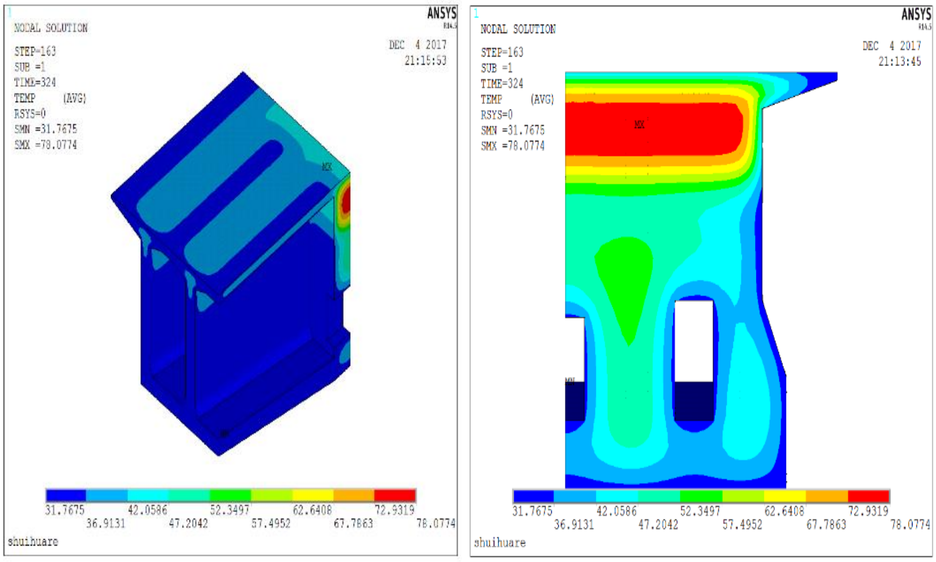
Table: Material and Thermal Characteristics data

C. Comparative analysis of measured results and numerical simulation

A comparative analysis of measured results and numerical simulation is discussed in this section. A nodal point of significant influence is selected and results compared. A nodal point with high-temperature influence situated in first and second layer measured points is simulated using ANSYS as shown in fig7, measured points in the first and second layer located during fieldwork are compared with the simulated results. In fig6 illustrates the highest temperature of the model in the first and the second layer. In fig (6 a.) the maximum temperature of the first layer at 78h after pouring is79. 76°C.Whereas in fig (6b.) the maximum temperature of the second layer at 324h after pouring is 78. 08°C.The results of the compared analysis between the measured result and numerical simulation result are represented in fig 7.

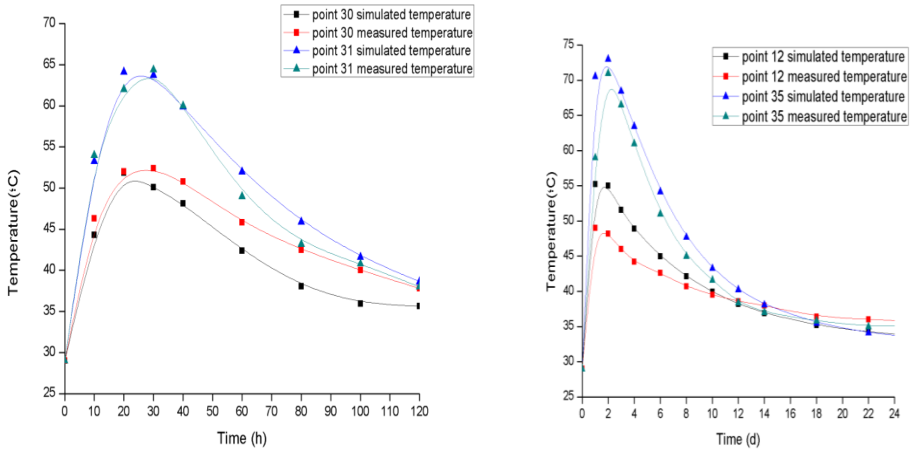


a. The first layer of the temperature field in 78h after pouringb. Isometric view of the first layer in 78h after pouring

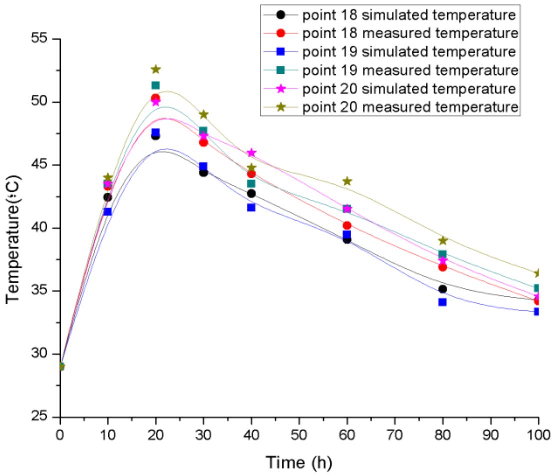


c. The second layer of the temperature field in 324h after pouring d. Isometric view of the second layer in 324h after

Fig6: The maximum temperature of the first and second layer in the temperature program



a. Measured and simulated temperature at measuring points 30, 31 b. Measured and simulated temperature at measuring points 12, 35



c. Measured and simulated temperature at measuring points 18, 19, and 20

Figure 7: Part of the measured temperature and simulated of the theoretical temperature curve

From Fig. 6 and Fig.7, it can be seen that the heat released by the hydration heat of the concrete after pouring causes the temperature went through an ascending and descending phases and gradually converge with the external ambient temperature. The trend of zero block temperature changes is generally consistent with the characteristics of the mass concrete. The thickness of these parts is different from the top, bottom reaching a temperature of 71.2 ºC. The thicker the board, the slower the temperature drop, and the longer the time required to achieve the same temperature as the external environment. In Fig.7the maximum temperature difference between the simulated temperature and the measured temperature is 2.7 ºC to 5 ºC.

After the concrete is poured, the roof is affected by the external environment, which may be due to the relatively small thickness of the roof. The comparison between the measured temperature and numerically simulated results is not very consistent, the main reason is that the day and night ambient temperature changes in the roof and the simulation of the ambient temperature was taken as average. The temperature of the web bottom is almost the same as the surface temperature and the temperature difference between the two is 12 ºC, the temperature difference gradually reduces until the room temperature is the same as the ambient temperature. The measured temperature curve is in good agreement with the numerical simulation result curve.

VI. CONCLUSION

The distribution of temperature in the process of hydration heat is a very complicated physical and chemical phenomenon. It is necessary to analyzed hydration heat of large volume of concrete members with zero blocks. Based on finite element simulation carried out on a bridge single box three chambers prestressed concrete zero block box girder model for hydration heat. The following conclusion can be drawn:

(1) During the process of hydration heat, the maximum temperature occurred at the thickest part of the component, the bottom temperature of the diaphragm was about 78.08 ºC in 3 days. The thicker the board, the slower the temperature drop, and the longer the time required to achieve the same temperature as the external environment.

(2) The first layer of concrete after pouring occurred in the largest part of the diaphragm and the web junction of the surface also at the whole surface. After the second layer of concrete pouring occurred at the junction of the old and new concrete the diaphragm and the web was 52.6ºC. It can be seen that with an increase in the amount of cement, the box beam concrete temperature gradually increases.

Therefore, the amount of cement in the box is important. The concrete hydration heat temperature has a very significant effect. The higher the cement dosage the higher the concrete hydration heat temperature. Therefore, for any high-speed railway precast box girder, the amount of cement must be controlled to reduce the temperature of concrete hydration in order to achieve the purpose of controlling temperature cracks. Based on the findings cement dosage can be reduced, to control the concrete temperature and determine the thermal performance parameters of the concrete under the premise of ensuring that the strength and other properties of the concrete are intact. In this paper, Cross-sectional size is taken into consideration, in order to reduce the hydration heat of concrete temperature and to ensure that the temperature difference between the box and the outside will not produce too much temperature cracks.

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