Research and Analysis on hydration heat effect of mass concrete for main tower cap of long-span self anchored suspension bridge

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Abstract. The self anchored suspension bridge on Jiancai North Road in Xi'an city is a typical cable structure. According to the force transmission characteristics of the cable, the main tower bearing platform is planned to adopt the construction method of laying embedded parts in the bottom layer and pouring the upper layer at one time, which is very different from the traditional layered and phased pouring of the bearing platform. In this paper, the finite element analysis software is used to carry out the fine modeling analysis of the foundation cap and its foundation temperature diffusion area, and the actual simulation of temperature and stress is carried out, and the "temperature stress asynchronous" effect caused by the bottom layer embedded parts and the upper layer pouring construction is studied; by analyzing the asynchronous difference of stress and temperature peak, the transfer law of temperature core area and the temperature field change caused by surface temperature control effect, the construction and monitoring measurement scheme is optimized.

1. Introduction

With the rapid development of economy and technology, the mass concrete project is increasing gradually. Since the 1930s, the research on the general concrete temperature field and stress field has been started. Water conservancy experts, represented by academician Zhu and Professor Wang, have also begun to study the king of general coagulation [1-2].

Japanese experts and scholars define the term "mass concrete" as follows: when the concrete structure is poured, it is affected by the hydration heat produced by the hydration reaction of the cementitious material in the concrete, the temperature difference between the inside and outside of the structure is greater than 25℃, and the minimum section size of the structure is greater than 0.8 m. The domestic explanation of "mass concrete" is as follows: the minimum section size of concrete structure during pouring is in the range of 1-3 m, and measures must be taken to avoid concrete with temperature difference greater than 25℃ caused by hydration heat [3].

There are some differences in the interpretation of mass concrete at home and abroad. Because the simple explanation of the size of concrete structure section is not comprehensive, the influence of the heat generated by the reaction of cementitious material and water on concrete structure is to consider the factors such as the composition of concrete materials, ambient temperature, atmospheric environment, structure size, construction conditions, temperature control measures and other factors.

At present, the construction control of mass concrete has always been a difficult problem in the engineering field. In the cold northwest region, there is a low temperature period of 90-180 days every
year. According to the construction period requirements of various projects, some mass concrete projects have to be constructed in the low temperature environment\(^4\)\(^-\)\(^5\).

For the cable structure, the temperature field of the mass concrete of the main tower bearing platform is more complex. The embedded parts are used in the main tower bearing platform of the self anchored suspension bridge on Jiancai North Road in Xi'an city. Different from the traditional one-time pouring of the bearing platform, the embedded parts must be set after the bottom concrete pouring, after the last pouring, the pouring should be continued according to the variable section caused by the embedded parts.

2. Engineering survey
The self anchored suspension bridge on Jiancai North Road in Xi'an city crosses the Ba River. The main tower is a special-shaped steel tower column. The bearing platform is 5m high and the plane size is 35.25×29.00m. The concrete is C40 micro expansion concrete. In order to prevent the normal use of the structure from being damaged due to the influence of cement hydration heat, it is necessary to analyze the concrete temperature field of the pile cap. The overall structure of the bridge is shown in Figure 1.

![Figure 1. Panorama of self anchored suspension bridge on Jiancai North Road](image)

3. Heat of hydration theory and boundary conditions

3.1. Theory of concrete hydration heat
At present, there are three mainstream methods, namely exponential, hyperbolic and experimental determination\(^6\)\(^-\)\(^7\), as follows:

- Exponential formula.
- Hyperbolic formula.
- Experimental determination.

3.2. Calculation adjustment and correction

- Simulation of boundary
  Due to the contact between the bottom of the pile cap and the foundation, the analysis of hydration heat in the pouring process of the pile cap will be affected by the foundation. Therefore, when establishing the model, it is necessary to simulate the foundation and set the material, thermal and mechanical parameters of the foundation, so as to truly and accurately simulate the influence of hydration heat on the pile cap structure\(^8\).

- Reasonable transformation and adjustment of the model
  Generally, the hydration heat analysis model has a large number of units, so it takes a long time to analyze. Moreover, it needs more time to analyze the multi condition conditions. If the model belongs to symmetric model, only 1/4 model can be established to reduce the analysis time. This can not only reduce the analysis time, but also help to view the analysis results in the center of the model\(^9\).

- Controlling shrinkage and creep
Creep calculation method can be user-defined or use the standard calculation method. In this paper, the shrinkage and creep of C40 concrete are set according to the standard. The elastic modulus reduction method is a simple calculation method of assuming creep and then reducing the elastic modulus of concrete, which is used in general hydration heat analysis. Because the elastic modulus reduction method is only applicable to the hydration heat analysis, in order to avoid misuse in the general construction stage analysis, it is defined separately in the hydration heat analysis control.

When the elastic modulus reduction method is used, in order to specify the element to calculate creep (connect the creep function with the material through the corresponding options in the material dialog box, and then connect the creep function with the element by assigning the material to the element), a creep calculation method needs to be defined [10-11], however, the creep calculation method defined here is not involved in the calculation of creep in hydration heat analysis.

4. Structure modeling and analysis
When calculating the hydration heat, the pile and soil are simulated with the characteristics of the foundation. Due to the surface convection and heat conduction, the thermal characteristics of the foundation are defined in the program, so that the real situation of heat exchange between the pile cap and the foundation can be simulated approximately. In the numerical simulation analysis, the following assumptions are made [12-13]:

- It is assumed that the mass concrete is homogeneous, the initial temperature is the same, and the heating rate of each joint is the same;
- Ignore the influence of reinforcement and other materials in the mass concrete.

4.1. Parameter selection
Parameters of platform and foundation are shown in Table 1-2.

|  | Specific heat capacity (kJ/(kN·℃)) | Thermal conductivity (kJ/(m·kN·℃)) | Coefficient of linear expansion (1/°C) |
|---|---|---|---|
| Platform | 98.9 | 8.4 | 0.00001 |

|  | Specific heat capacity (kJ/(kN·℃)) | Thermal conductivity (kJ/(m·kN·℃)) | Coefficient of linear expansion (1/°C) |
|---|---|---|---|
| Foundation | 85.7 | 7.0 | - |

4.2. Model establishment
The finite element analysis software is used to analyze and calculate the real construction process of the pile cap. The foundation is built into a component with specific heat and heat conductivity characteristics, and a quarter model is established considering the symmetry of the structure. It is divided into 6444 units and 7820 nodes. The geometric model is shown in Figure 2.
5. Structural modeling and analysis

5.1. Temperature nephogram
The construction process is completed in the order of bottom pouring-embedded parts and upper layer pouring, and is simulated according to the actual situation. The maximum temperature is 72°C and gradually decreases after about 120 hours. The typical temperature field diagram is shown in Figure 3-6.

Figure 3. The bottom layer is just poured  Figure 4. The upper layer has just been poured
Figure 5. The Upper layer curing for 120h  Figure 6. The Upper layer curing for 1000h

5.2. Stress nephogram
The construction process is completed in the order of bottom pouring-embedded parts and upper layer pouring, and is simulated according to the actual situation. The typical temperature field diagram is shown in Figure 7-10.

Figure 7. The bottom layer is just poured  Figure 8. The upper layer has just been poured
5.3. Analysis results of key nodes

According to the cloud chart, it is obvious that there are multiple stress and temperature control points in the whole pouring process. According to the data integration analysis, a total of six nodes are used for temperature and stress analysis, as shown in Table 3-4.

Table 3. Temperature change trend

| Time (h) | Temperature (℃) |
|---------|-----------------|
| 0       | 80              |
| 200     | 70              |
| 400     | 60              |
| 600     | 50              |
| 800     | 40              |
| 1000    | 30              |
| 1200    | 20              |

Table 4. Stress variation trend

| Time (h) | Stress (Mpa) |
|---------|--------------|
| 0       | 0.4          |
| 200     | 0.3          |
| 400     | 0.2          |
| 600     | 0.1          |
| 800     | 0            |
| 1000    | -0.1         |
| 1200    | -0.2         |
The symbols in the figure are as follows:
Upper center point (Blue Diamond). Bottom center point (X symbol). Center point of divider (Red rectangle). Upper outer point (Blue snowflake). Bottom outer point (Orange circle). Outer point of divide (Green Triangle).

5.4. Analysis of calculation results
It can be seen from the table and picture data that the temperature field of bearing platform with embedded parts is obviously different from that of traditional bearing platform:

- The temperature stress asynchrony effect is very obvious. The internal heating effect was obvious in the first 100 hours, and began to decline after the maximum temperature reached 72°C. The decline slope was slightly different according to the temperature control effect, but the overall trend was rapid decline; however, with the increase of curing time, the increase of internal stress is gradually significant and the hierarchy is distinguished, that is, the internal tensile stress increases gradually, while the external tensile stress decreases gradually;
- The bearing cap is poured in stages, and the effect of temperature core transfer caused by this construction method is remarkable. The concrete performance is as follows: after the bottom layer pouring is completed, the temperature in the whole 0-1.5m thickness range is relatively uniform. When the embedded parts are arranged and the upper layer is poured, the core area of temperature is the top of the bottom layer. After about 65h, the core gradually rises and spreads from the original area to the geometric center of the whole cushion cap;
- The temperature control effect of the surface layer is obviously related to the stress distribution. The specific performance is as follows: the atmospheric contact of this model is based on the same temperature transfer effect simulation, and the stress effect caused by it has shown asynchronous difference with the temperature. The improvement of the insulation effect of the external interface will lead to the balance of the internal and external temperature difference, the decrease of the tensile stress, and the decrease of the insulation effect of the external interface will significantly increase the internal tensile stress, resulting in the generation of uneven cracks.

6. Conclusion
- The temperature control effect of the surface layer is obviously related to the stress distribution. The specific performance is as follows: the atmospheric contact of this model is based on the same temperature transfer effect simulation, and the stress effect caused by it has shown asynchronous difference with the temperature. The improvement of the insulation effect of the external interface will lead to the balance of the internal and external temperature difference, the decrease of the tensile stress, and the decrease of the insulation effect of the external interface will significantly increase the internal tensile stress, resulting in the generation of uneven cracks.

- Considering the general differences of construction methods, it is suggested that in the construction stage, temperature measuring devices should be set up at each partition surface and partition layer for real-time measurement. In addition, it is necessary to arrange at least three rows of temperature control measuring points in the geometric center, separation point, external and other parts. Each temperature control measuring point is divided into internal and external, and can be added if conditions permit;
- The stress peak is always later than the peak temperature, because the uneven temperature difference will be generated after the local temperature rise. The uneven temperature difference gradually accumulates with time and gradually forms the uneven stress. The tensile stress will be generated after the increase of the tensile stress exceeds the expansion value of the concrete, and the cracks will be generated with the increase of the tensile stress;
- Tube cooling is recommended for internal temperature control. The layout of pipe cooling can be carried out around the temperature stress distribution nephogram, but it needs to meet the requirements of structure and stress; at the same time, for the external part in contact with the atmosphere, thermal insulation is needed to prevent temperature interlayer; at the same time, the micro
expansion concrete can be used to improve the overall performance, and the vibration can be strengthened in the parts where the temperature stress is concentrated.

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