Study on Temperature Control of Gravity Anchorage without Cooling Water

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Abstract. This paper uses Midas Fea simulation software to analyze the hydration heat of a suspension bridge anchorage mass concrete construction without cooling water. According to specific boundary conditions and convection coefficients, the concrete heating process and cooling process are simulated. Analyze the influence of surface air convection coefficient on the surface tensile stress of the cast layer, and the influence of the pouring interval on the interlayer stress of the anchor block, and the temperature difference between the inside and outside of the concrete when the anchor block is layered. It is found that reducing the surface convection coefficient of the pouring layer can effectively improve the stress condition, and the pouring interval has little effect on the stress.

Keywords. Anchorage hydration heat without cooling water  air convection coefficient  pouring interval.

1. Introduction

During the curing period of the integrally poured mass concrete, the temperature shrinkage and deformation caused by the cooling is relatively large. Temperature shrinkage deformation will generate tensile stress in the structure and its surface under constrained conditions. When the tensile stress exceeds the tensile strength of the concrete at the corresponding age, or the confined shrinkage deformation of the concrete exceeds the ultimate tensile strain capacity of the concrete, cracks will occur. [1] Therefore, in the process of mass concrete construction, to avoid excessive temperature stress, prevent the generation of temperature cracks or control the cracks within a certain limit, temperature control must be carried out. The main goal of temperature control is to make the temperature field change inside the mass concrete develop according to the expected goal, which can be divided (1) reduce the maximum adiabatic temperature rise and the maximum temperature peak; (2) control the temperature gradient of the surface concrete to reduce The temperature difference between inside and outside prevents the cold shock effect; (3) Control the cooling rate of concrete; (4) Control the temperature difference between upper and lower layers to prevent possible interlayer cracks and reduce interlayer restraint. [2] The construction temperature control of large-volume concrete structures should be carried out from the design stage. The main contents are: (1) perfect structural design and improve constraint conditions; (2) optimize design mix ratio and rational raw material selection; (3) Optimize construction technology and strengthen construction management; (4) Adopt heat reduction and insulation measures; (5) Scientific prediction and accurate monitoring. [3] The general principle of temperature control can be summarized as "internal reduction and external protection". "Internal drop" refers to reducing the amount of cement by optimizing the mix ratio and reducing the maximum adiabatic temperature rise of concrete. Arrange the cooling water pipes before pouring, keep the water pipes with cold water during the pouring process, to achieve the purpose of reducing the temperature peak and delay the time of the
temperature peak, and in the cooling stage after the completion of all the concrete pouring, the temperature of the cooling water pipe is not low. The cooling rate is controlled by circulating water with a maximum temperature of 10 degrees Celsius inside the concrete. "External protection" refers to covering the surface of the concrete with plastic film and geotextile for heat preservation and moisturizing after the final set of the concrete, to avoid the excessive temperature difference between the inside and the outside and the cracking of the concrete surface caused by the evaporation of water. The use of non-cooling water pipes for mass concrete construction can only reduce the maximum adiabatic temperature rise of concrete from the aspect of optimizing the mix ratio. For the construction that can meet the requirements of the specification, not using the cooling water pipe can effectively save materials and manpower, and at the same time, it can also avoid the rust of the water pipe caused by the late grouting of the cooling water pipe and the lack of compactness.

2. Project Overview
Gravity rock-socketed anchorage is used on both sides of a ground anchor suspension bridge, and an expanded foundation is used for anchorage foundation. Gravity anchorage is composed of anchor block, anchor chamber, loose cable saddle foundation, saddle, and anchorage system. C30 concrete is used for the rest of the anchorage except the support pier and anchor chamber, and C30 micro-expansion concrete is used for the post-pouring section. The anchor block is a C30 mass concrete structure of 50×24×28m (length × width × height of the maximum section). The mass uncooled water pipe casting process is adopted for the casting of anchorage concrete, and the construction process of "left and right blocks and vertical layers" is adopted. The vertical casting thickness is 2m, and each casting is 28m for left and right sides, which is finished 14 times.

3. Calculation of Heat of Hydration and Simulation of Construction
3.1. Material and Mix Ratio
Fly ash: F class I grade ash
Admixture: water reducing agent
Crushed stone: two-stage graded gravel
Sand: river sand
Water: Groundwater

Table 1. A slightly more complex table with a narrow caption.

| Material consumption (kg/m³) | Compressive strength (MPa) | Setting time (h) |
|-----------------------------|---------------------------|-----------------|
| Cement | Fly ash | Sand | Gavel | Water | Admixture | 7d | 28d | 60d | Initial set | Permanent set |
| 280 | 160 | 813 | 1077 | 140 | 4.4 | 30.9 | 35 | 42 | 7 | 10 |

3.2. Definition of Model Parameters
C30 concrete has an elastic modulus of 30MPa, a density of 240kg/m³, a Poisson's ratio of 0.2, a thermal conductivity of 10.6kJ/(m•h•℃) and specific heat of 0.96kJ/(kg•℃). When defining the shrinkage and creep of concrete, according to the CEB-FIP specification, the 28d compressive strength of C30 concrete is 30000kN/m², the annual average relative humidity is 65%, and the concrete material is set to 3d when the material starts to shrink.

3.3. FEA Model
According to the actual construction situation, choose the right anchor block, establish the anchor foundation, and four-layer anchor block model for simulation calculation. The model sets a fixed boundary at the bottom of the foundation, takes the average atmospheric temperature of 20℃, and applies it to the bottom of the foundation according to the forced temperature. A convection boundary
is set for the contact between the anchor block and the template and the contact surface with the surrounding rock mass. The convection coefficient is 14W/(m²•°C). Considering that the top surface of the cast layer is in contact with air, the convection boundary is also set, and the air convection coefficient is 4W/(m²•°C), the model in figure 1.

![Figure 1. FEA Model.](image)

Working condition 1, the temperature of fly ash cement concrete is 20°C, and the maximum adiabatic temperature rise of C30 concrete is 36.8°C and the temperature conductivity coefficient is 0.529 according to the Japanese JSCE2002 standard.

Working condition 2, changing the temperature of fly ash cement concrete to 10°C under other conditions unchanged, its adiabatic temperature rise is 33°C, and the temperature conductivity coefficient is 0.309.

Analyze the calculation results of working conditions one and two. When other conditions remain unchanged, the temperature of fly ash concrete changes from 20°C to 10°C. During the pouring of each layer of concrete, the peak temperature and the temperature difference between inside and outside will be reduced. The stress value has been reduced.

![Figure 2. Temperature change curve of key points in the centre of each layer under working condition 1.](image)

![Figure 3. Temperature change curve of key points on the surface of each layer under working condition 1.](image)
Figure 4. Stress development curve of key points in the centre of each layer under working condition 1.

Analyze the calculation result of working condition 2, under the condition that the temperature difference between the inside and outside of each layer of concrete is not more than 25℃, the stress of the key points of the concrete 4d-6d after the completion of the pouring exceeds the allowable tensile stress, indicating that the external environment temperature is 25℃. When the cement dosage is 240kg/m³, the adiabatic temperature rise of fly ash cement concrete at 20°C is 36.8℃, and the temperature conductivity coefficient is 0.529. If the cooling pipe is not used, the stress will exceed the allowable stress.

The calculation results show that the temperature of the first layer of anchor blocks reaches a peak of 44℃ 5.5 days after the completion of pouring, and then enters a slow cooling stage. The second layer of anchor blocks reached a peak temperature of 49.6°C 6.5 days after pouring, and then slowly cooled to 48℃, and stabilized. The temperature of the third layer of anchor blocks reached a peak of 50.7 °C 7 days after the completion of pouring, and then entered a slow cooling stage, and then stabilized at 50°C. With the heating process of the fourth layer of anchor blocks, the central temperature of the third layer increased to 51.6 °C. The temperature of the fourth layer of anchor blocks reached a peak of 50.8°C 7 days after the completion of pouring. The temperature change curves of the key points of each layer of concrete are shown in figure 6 and figure 7.

Considering the influence of the concrete's weight, the compressive stress of the first layer will increase with the application of subsequent pouring layers. The maximum stress of the first layer does not exceed the allowable stress. The pouring of the second layer anchor block is completed, and the maximum stress of the key point exceeds the allowable stress at this point. When the third layer is completed, the stress of the key point is less than the allowable stress. The pouring of the third layer of anchor blocks is completed, and the maximum stress at the key point exceeds the allowable stress at this point. When the third layer is poured, the stress at the key point is less than the allowable stress. The stress development curves of key points of each layer of concrete are shown in figure 8 and figure 9.
The Influence of Air Convection Coefficient on the Surface of the Pouring Layer

In the actual construction process, the thermal insulation material used on the surface of the cast layer has its specific thermal conductivity. By keeping other parameters constant in the model and changing the size of the air convection coefficient, the influence of the thermal insulation measures on the surface of the cast layer on the stress and temperature of the cast concrete was analysed.

4.1. The Influence of Air Convection Coefficient on the Stress of Each Layer of Concrete

The calculation results show that the tensile stress at the central point of the cast layer surface increases with the increase of the convection coefficient, the weakening of the thermal insulation effect of the concrete surface will increase the risk of concrete surface cracking. The stress development curves of each layer of concrete under different air convection coefficients are shown in figures 11-14. Analyzing the relationship between the stress of the second layer surface point and the convection coefficient, it can be seen that when the air convection coefficient is greater than equal to 6, the stress value of the surface central point is greater than the allowable stress at this point, as shown in figure 10.
**Figure 10.** The relationship between the maximum stress on the second layer surface and different air convection coefficients.

**Figure 11.** Stress development curve of the central point on the first layer surface under different convection coefficients.

**Figure 12.** Stress development curve of the central point on the second layer surface under different convection coefficients.

**Figure 13.** Stress development curve of the third layer surface central point under different convection coefficients.

**Figure 14.** Stress development curve of the central point of the fourth layer surface under different convection coefficients.
4.2. The Influence of Air Convection Coefficient on the Temperature of Each Layer of Concrete

When the surface air convection coefficient of the last layer is 2, the highest temperature in the center of the fourth layer is 53.1°C, and when the surface air convection coefficient is 14, the highest temperature in the center is 47°C, as shown in Figure 15. The peak temperature of the center of the cast layer decreases with the increase of the air convection coefficient on the surface of the cast layer. The temperature difference between the inside and outside of the concrete layer decreases with the increase of the air convection coefficient, as shown in Figure 16.

Figure 15. These two figures have been placed side-by-side to save space. Justify the caption.

Figure 16. These two figures have been placed side-by-side to save space. Justify the caption.

5. The Influence of Pouring Time Interval

The mass concrete specification requires that the time interval for layered pouring should not exceed seven days, but in actual construction, due to the influence of the construction environment (such as the rainy season), it is difficult to ensure that the pouring interval is within the range of 7 days. Through model and analysis of the impact of different interlayer pouring intervals, it is found that after the fourth layer pouring is completed, the surface central temperature of the anchor blocks of the first and second layers will decrease with the increase of the interval time, which is roughly in a linear relationship, see Figure 18. The maximum temperature difference between the highest temperature at the center and the surface temperature of the layering decreases with the extension of the pouring interval, as shown in Figure 19. The influence of different pouring time intervals on the stress of each layered interface is quite small. Take the stress at the central point of the top surface of the second layer as an example, as shown in Figure 17. The maximum tensile stress is 0.247 MPa when the pouring interval is five days, and the maximum tensile stress is 0.25 MPa when the interval is ten days.

Figure 17. In this case simply justify the caption so that it is as the same width as the graphic.
6. Conclusion
This paper uses Midas FEA software to analyze the effects of three factors: materials, surface insulation measures, and interlayer pouring interval on the construction of suspension bridge's anchorage mass concrete without cooling water, the following conclusions can be drawn.

(1) The reduction of the temperature of fly ash cement can reduce the maximum adiabatic temperature rise and thermal conductivity of concrete, reduce the temperature difference between the inside and outside of the concrete, and improve the surface tensile stress during layered pouring.

(2) The surface tensile stress of the pouring layer is proportional to the air convection coefficient. Reducing the air convection coefficient and strengthening the thermal insulation effect can improve the surface tensile stress of the concrete.

(3) For large-volume concrete constructed by layered pouring without cold water pipes, the interlayer pouring interval is in the range of 5 to 10 days, which has no effect on the maximum tensile stress on the surface. The maximum temperature of the center of the interlayer and the surface temperature will vary with the interval time increases and decreases.

When mass concrete is constructed without cooling water, strictly control the raw materials, reduce the hydration heat and thermal conductivity of the concrete itself, strengthen the thermal insulation effect and control the temperature difference between inside and outside, which can effectively reduce the tensile stress on the concrete surface and reduce the risk of cracking.

For large-volume concrete constructed without cooling water, it is necessary to determine the raw materials, ambient temperature, concrete molding temperature, insulation measures, boundary constraints, and layer thickness according to the actual construction environment to formulate a complete construction plan.

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