Study on Concrete Stress during Construction for Large Pumping Station Flow Channel Structure under Thick-layer Pouring Condition

Xuerui Zheng¹, Zhenzhong Shen¹, Sheng Qiang¹*, Pu Xu²
¹ College of Water Conservancy and Hydropower Engineering, Hohai University, Nanjing 210098, China
² Shanghai Municipal Engineering Design Institute Co., Ltd., Shanghai 200092, China
*Corresponding author’s e-mail: sqiang2118@hhu.edu.cn

Abstract: Large pumping stations have the characteristics of complex structure, large amount of concrete pouring block, easy cracking of concrete and long construction period, etc. For the stress safety of the flow channel structure during construction period, temperature control simulation for a large pumping station during construction period is carried out. By comparing and analyzing the variation law of temperature field and stress field of the two types of pouring layers which are one 6m layer and two 3m layers, the influence of thick-layer pouring on concrete stress is studied. The simulation results show that thick-layer pouring may cause the increasement of tensile stress peak in concrete structure, but this adverse effect can be eliminated by appropriate temperature control measures. The effect of the same temperature control measures on the reduction of tensile stress of thick-layer concrete structure is more obvious. Thick-layer pouring can shorten the construction cycle of pumping station under the premise of ensuring safety which has a wide application prospect in the field of concrete construction.

1. Introduction
In the construction process of mass concrete structure, how to prevent the temperature crack of concrete has always been the focus of engineering construction [1-2]. With the rapid development of infrastructure construction in China, under the premise of ensuring construction quality and safety, it is a new challenge for the project construction in the new era to reduce the construction difficulty and shorten the construction cycle to the maximum extent [3].

Yang Qiaope [4] analyzed the variation of temperature field and stress field of conventional pouring, short interval pouring and thick layer short interval pouring. The conclusion shows that under the premise of adopting reasonable temperature control measures, properly increasing the thickness of the pouring layer can meet the requirements of engineering crack prevention, which is beneficial to shortening the construction period and obtaining the benefit ahead of time. Qiang Sheng [5] thinks that the stress of concrete can meet the requirement under the condition of controlling pouring temperature, cooling of water pipe, surface insulation and other temperature control measures, although the thick layer pouring is unfavorable to the stress of concrete. Wang Haibo's research [6] shows that with the increase of the thickness of the concrete dam, the temperature gradient of the early dam body increases and the early tensile stress increases. This is a problem caused by thick layers, which must be solved by proper surface insulation measures.
At present, the academic and engineering circles have carried out some research on the influence of thick layer pouring of gate pier and concrete dam on the stress of concrete structure, but no attempt has been made on the thick layer pouring of large pumping station flow channel structure. So this article launches the research analysis from this aspect.

2. Simulation calculation model and parameters

According to the drawing of Huazi pumping station in Zhejiang Province, the finite element model was established by selecting two connecting holes. The main concrete structure of pumping station is 48 meters long, 23 meters wide and 13 meters high. Flow channel structure is 6 meters high. The finite element model of pumping station is shown in figure 2-1. The total number of cells is 76024 and the total number of nodes is 88096. The coordinate origin of Huazi pump station is located on the upper surface of the inlet flow channel roof. The Z axis is vertical, the X axis points to the current direction, and the Y axis points to the left bank according to the right-hand spiral rule.

The foundation material below the floor of the structure is mainly silty clay, C30 concrete is used for pile foundation structure, and C25 concrete is used for cushion structure. The concrete strength grade of the main structure of pumping station is C30 and the tensile strength of concrete is 3.0 MPa. The tensile strength of the concrete in the lower layer of the flow channel structure is increased by 20% when the tensile fiber is added into the concrete. The ultimate tensile strength of the flow channel structure reaches 3.6 MPa.

The thermodynamic parameters of various materials are shown in Table 2-1.

| Category   | Thermal convection (kJ/m·h·℃) | Specific heat (kJ/kg·℃) | Thermal diffusivity (m²·h) | Adiabatic temperature rise (℃) | Linear expansion coefficient (x10⁻⁶/℃) | Final value of autogenous volume deformation (x10⁻⁶) | Density (kg/m³) | Final elasticity modulus (MPa) | Poisson ratio |
|------------|-------------------------------|--------------------------|---------------------------|--------------------------------|---------------------------------------|----------------------------------------|----------------|-------------------------------|----------------|
| C25        | 6.57                          | 0.93                     | 0.0031                    | 38                             | 9.49                                  | 65.27                                   | 2261           | 28000                         | 0.167          |
| C30        | 10.82                         | 0.89                     | 0.0053                    | 51.3                           | 8.90                                  | 77.26                                   | 2318           | 35000                         | 0.167          |
| Silty clay | 2.41                          | 1.91                     | 0.0012                    | /                              | 8.00                                  | /                                       | 1793           | 10                            | 0.300          |

In order to facilitate the calculation, the monthly mean temperature of many years is fitted into a cosine curve.

\[ T_{m}(\tau) = 17.1 + 12 \times \cos \left[ \frac{\tau}{6}(\tau - 7.2) \right] \]  

(2-1)

In the form:  \( \tau \)  Time (month).

In the simulation calculation of the temperature field, the surrounding and bottom surface of the foundation is adiabatic boundary, and the upper surface is the heat dissipation boundary. The symmetry plane of the structure is the adiabatic boundary. Construction temporary seam surface, structure permanent seam surface when not covered as the heat dissipation boundary, after covering is the adiabatic boundary. The other surfaces are heat dissipation boundaries.

In the simulation calculation of the stress field, normal constraint is applied to the surrounding and bottom surface of the foundation, and the upper surface is free boundary. Normal constraint is applied.
to the symmetry plane of the structure, and structural permanent seam surface is free boundary. Other surfaces are free boundaries.

3. Calculation condition and result analysis

3.1. Stratified pouring condition of flow channel structure

The condition series contains two cases for layered pouring of the flow channel structure of the pumping station. The flow channel structure is divided into two layers, the lower structure is 3m high, the upper structure is 3m high, and the interval between the two layers is 20 days. In case 1, no cooling pipe measures were taken on both of the upper and lower layers. In case 2, no cooling pipe measures were taken on the upper layers, but the lower layer carries on the water pipe cooling. The pouring time of the main structure of pumping station are shown in Table 3-1.

The finite element method is used to simulate the construction period of the main structure of pumping station. Under different pouring schemes, the maximum tensile stress and maximum temperature of the pumping station can be obtained. Limited to space, this paper only selects the central section of the inlet passage to explain.

Table 3-1. Hierarchical pouring schedule of Huazi pumping Station.

| Pouring block name | Pouring time | Pouring temperature (℃) | Pouring block name | Pouring time | Pouring temperature (℃) |
|--------------------|--------------|-------------------------|--------------------|--------------|-------------------------|
| Outlet channel floor | January 18 | 18                      | Lower layer of inlet channel | July 10 | 35                      |
| Inlet channel floor | January 30 | 18                      | Upper layer of inlet channel | July 30 | 35                      |
| Post-pouring floor | March 21 | 22                      | Upper partition wall of outlet channel | Aug 22 | 35                      |
| Side pier wall | April 8 | 22                      | Upper partition wall of outlet channel | Aug 25 | 35                      |
| Lower layer of outlet channel | July 4 | 35                      | Post-pouring channel | Oct 20 | 22                      |
| Upper layer of outlet channel | July 24 | 35                      |                     |              |                         |

The finite element method is used to simulate the construction period of the main structure of pumping station. Under different pouring schemes, the maximum tensile stress and maximum temperature of the pumping station can be obtained. Limited to space, this paper only selects the central section of the inlet passage to explain.

Figure 3-1. Case 1 temperature Envelope Diagram and stress Envelope Diagram

(a) Temperature envelope diagram

(b) Stress envelope diagram
3.2. Integral pouring condition of flow channel structure

The condition series contains two cases for integral pouring of the flow channel structure of the pumping station. In case 3, no cooling pipe measures were taken. In case 4, no cooling pipe measures were taken on the upper layers, but the lower layer carries on the same water pipe cooling as that of working condition 2. The pouring time of the main structure of pumping station are shown in Table 3-2.

Table 3-2. Hierarchical pouring schedule of Huazi pumping Station.

| Pouring block name | Pouring time | Pouring temperature (℃) | Pouring block name | Pouring time | Pouring temperature (℃) |
|--------------------|--------------|-------------------------|--------------------|--------------|-------------------------|
| Outlet channel floor | Jan 18 | 18 | inlet channel | July 10 | 35 |
| Inlet channel floor | Jan 30 | 18 | Upper partition wall of outlet channel | Aug 2 | 35 |
| Post-pouring floor | Mar 21 | 22 | Upper partition wall of outlet channel | Aug 5 | 35 |
| Side pier wall outlet channel | Apr 8 | 22 | Post-pouring channel | Sept 20 | 22 |
Figure 3-4. Case 4 temperature Envelope Diagram and stress Envelope Diagram

3.3. Characteristic Point temperature and stress Analysis
Select the Characteristic point 1 (X = 8.2, Y = 5.5, Z = -5.5) on the lower center section of the inlet channel, and the Characteristic point 2 (X = 9.2, Y = 5.5, Z = -3.01) on the upper center section of the inlet channel. The temperature envelope diagram and the stress envelope diagram of the characteristic points are shown in Fig. 3-5 and Fig. 3-6. In order to compare the change of temperature, the age of concrete in the diagram is its own age, and the pouring time is not considered.

Table 3-3. Maximum tensile stress of lower concrete

|                     | Layered pouring (3mx2) | Integral pouring (6m) |
|---------------------|------------------------|-----------------------|
| Without pipe cooling| 4.39 MPa               | 4.51 MPa              |
| pipe cooling in lower layer | 3.58 MPa          | 3.10 MPa              |
It can be seen from the curve of stress duration that the early stress of concrete with water pipe cooling increases rapidly. Under the condition of the same temperature control measures, the maximum tensile stress of the Integral concrete is less than that of the layered concrete. Under the condition of no water pipe cooling, the tensile stress of the lower layer concrete exceeds the allowable tensile stress. The maximum tensile stress of Integral concrete is greater than that of layered concrete.

For layered pouring, the maximum tensile stress of the lower layer concrete decreases by 0.81 MPa after the water pipe cooling measures are taken. For Integral pouring, the maximum tensile stress of the lower layer concrete decreases by 1.41 MPa after the water pipe cooling measures are taken.

Under the condition of the same temperature control measures, the construction period can be shortened by 20 days by adopting the integral pouring method.

4. Conclusion

The main results are as follows:

(1) The temperature control measures may lead to rapid increasement of concrete internal stress in early age, but it is helpful to reduce the maximum tensile stress.

(2) Compared with the layered pouring, if no water cooling applied, the integral pouring of the channel will induce higher tensile stress, but extent of the stress increasement is small.

(3) If the same temperature control measures are taken, the maximum tensile stress of concrete in the lower part of the channel will decrease 1.41MPa when it is poured with one 6m layer, while decreases 0.81MPa when it is poured with two 3m layers. It can be seen that the temperature control measures have a stronger effect on the thick-layer pouring, which can reduce the residual stress and reduce the time cost of construction period.

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