

## Simulation Analysis on Mass Concrete Temperature Field of Lock Floor Layered Pouring

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Abstract: Based on the background of navigation lock structure engineering in Changsha Integrated Hub, this study used Parametric Design Language (APDL) compilation command on the finite element program ANSAYS platforms to simulate the temperature field of the layered pouring process about the lower lock head. The temperature contour map and the change laws of temperature field with time in each different levels of the floor were obtained. And compared with the actual instrument measurement data, the feasibility of the simulation analysis was concluded. Then, this study optimized the pouring process, obtained the suitable methods of layered pouring and put forward the measures to reduce the concrete temperature crack.

Key words: Lock floor, pouring temperature field, heat of hydration, APDL.

## 1. Introduction

Mass concrete pouring has been widely used in the dock, ship lock and dam project. The mass concrete project has the characteristics of large volume and low thermal conductivity, and it is easy to produce temperature crack due to the large number of hydration heat in the pouring process. Data shows that most of the mass concrete structure engineering has appeared cracks during the construction period, and the temperature control problem has gradually attracted the attention of the engineering and academic circles. The report of International Commission on Large Dams (ICOLD) in 1988 for dam work status displayed that the vast majority of concrete dams which had been built in the world, more or less, have temperature cracks, and that there were 30 of the 243 suffered catastrophic damage concrete dams were caused by the temperature problem [1]. Lock floor belongs to the mass concrete structure and the crack

caused by the improper temperature control is widespread.

In this paper, authors used the finite element software ANSYS combined with practical engineering to get the simulation analysis of the lock floor structure temperature field in construction process. Also, authors verified the feasibility of the simulation analysis compared with field instruments monitoring results, and then optimize the floor layered pouring to obtain appropriate pouring project.

## 2. Engineering Situation

Xiangjiang Changsha integrated hub lock project is located on the left bank in the left branch of the river. It is a double lock and they have same approaches. The lock level is 2,000 t, and the effective size of the chamber is 280 m\*34 m\* 4.5 m (length\* width\* water depth on sill). Also it meets 1,000 t barge top four ships and 2,000 t barges op two ships safety getting through the lock and dam capacity requirements. The design passing capacity is 94 million tons (two-way double lock), and it will set aside the third-line lock.

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For timely, comprehensive and accurate grasp of on-site pouring concrete internal temperature change situation and it needs temperature monitoring of lower head lock floor in order to analyze the influence of temperature stress on the cracks, so as to verify the original temperature control standards and further improve the temperature control measures according to actual situation. Therefore, the control parameters will be provided to determine the concrete pouring closed time of the lock chamber and the phase 2 concrete of head lock structure. According to the construction progress organizing monitoring instruments and equipment safety buried in time, through the observation, abundant monitoring results data.

## 3. Achieve Unsteady Temperature Field

## 3.1 Layered Pouring Concrete Situation

The lock floor of lower head structure under the second line in the bottom was poured by four layers. The pouring thickness were 2 m, 1.5 m, 3.1 m and 0.9 m respectively and the pouring interval time were 3 days, 3 days, 7 days and 3 days respectively. The basic condition of the concrete pouring is shown in Fig. 1.

The actual layered pouring condition selected the calculation model. Because of comprehensive hub lock heads structure in Changsha adopted the overall dock structure [2]. By adopting the method of floor setting up two 1.5 m wide construction joints, the originally 62 m wide plate was divided into three

segments. Length of the middle was 20 m, and the other sides were 19.5 m. In this simulation analysis, we selected the middle period of structure and the 3D model as shown in Fig. 2. The concrete volume was about 2,625 m<sup>3</sup> and used C25 concrete. The concrete mix proportion is shown in Table 1.

#### 3.2 Monitoring Instrument Embedment

According to the "Xiangjiang river in Changsha comprehensive ship lock engineering mass concrete temperature monitoring plan", authors decorated a total of 175 thermometer, and divided them into 5 layers and each layer was 35. The embedding position is shown in Fig. 3. The thermometer was embedded in concrete pouring level and it should be fixed installed before concrete pouring. The thermometer must be kept horizontal and the embedding position error must be controlled within 5 cm.

### 3.3 Construction of 3D Finite Element Model

The mass concrete is usually poured by layer in order to reduce the temperature, and the lock floor was poured by the method of setting up wide construction joints in the process of simulation analysis. Here, authors should not only consider the temperature transfer of the bottom plate and foundation rock, and also consider the transfer of bottom boundary with outside air convection. The length of the selected model is 20 m, while the width is 17.5 m, and the height is 7.5 m. It need to use class 2, class 3 and class 4



Fig. 1 Floor concrete pouring scheme.



Fig. 2 The 3D model of the structure.

Table 1 Mixproportion of concrete.

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Concrete materials per cubic meter	Value(kg)
Water	154
Cement	180
Fly ash	107
Slag	72
Sand	802
Grait(20-40)	307
Admixture(0.8%)	2.86
Water-cement ratio	0.43

boundary conditions [3]. Structural model is relatively simple; the process could be realized by the operation of ANSYS graphical user and the APDL programming function.

According to the structural characteristics of the ship lock, geology, and terrain conditions, authors selected the following ranges as the finite element calculation area, choosing among floor 20 m segment as the body of the temperature field analysis; bedrock 0 m to 30 m deep as the original base and taken long the vertical axis of the gate to extend 50 m as a lateral boundary at the vertical axis of the bedrock; selected the actual structure as the upper boundary.



Fig. 3 The thermometer embedment position.

The thermal unit adopts SOLID70 in ANSYS structural analysis which has a total of eight nodes and each node has only one temperature degree of freedom. It can be used for 3D steady-state and transient thermal analysis of the problem because there are three directions of heat conduction ability and it can achieve the uniform heat transfer [4]. SOLID70 unit has an "element birth and death" function, it can activate each layer concrete respectively according to the construction pouring progress. And then authors use the DO while loop language controls and applies the layers of the concrete hydration heat as well as the convective boundary conditions to achieve the actual casting simulation. Using mapped meshing and selecting the unit side length of 0.5 m are for comparing with the results of the actual monitoring instrument. The finite element discrete model is shown in Fig. 4, and we concluded that the node number is 79498.

#### 3.4 Construction of 3D Finite Element Model

#### 3.4.1 Environment Temperature

According to the scene of the Changsha comprehensive hub construction condition, authors obtained the meteorological elements data during the construction and extract the value of what authors need. After collating, defining the temperature condition in the finite element analysis is as follows: the first layer pouring air temperature was 33 °C, the 2nd was 27 °C, the third layer was 34 °C and the fourth layer was 29 °C. In layered pouring temperature field analysis, authors need



Fig. 4 The finite element discrete model.

to set up the external environment temperature boundary conditions on the side of the concrete and the top surface of each layer. In addition, the concrete temperature load on the top of the layer should be removed in the next layer of construction and give different thermal conductivity coefficient and so on, until four layers of concrete pouring.

3.4.2 Thermodynamic Parameters of Concrete

In the process of calculation, the hydration heat of cement has been taken as the main temperature load on the each activation unit node. Adopt the compound exponential by Zhu [5] academician, which was expressed as:

$$Q(t) = Q_0 \left( 1 - e^{-at^b} \right)$$
 (1)

where: Q(t) is concrete hydration heat;  $Q_0$  is the final heat of hydration; *a* and *b* are coefficients.

 $Q_0$  and *a*, *b* should be determined based on on-site construction of concrete mix experimentally or can also get reverse thrust based on field data. Here, authors passed the field test results of rough calculation, and calculated according to Table 2.

In ANSYS, the calculated value of hydration heat cannot simply be applied as boundary conditions but to be applied by heat generation rate HGEN [6], which is expressed as:

$$HGEN = W_C dQ(t)/dt$$
<sup>(2)</sup>

where: HGEN is heat of hydration production rate of concrete,  $W/m^3$ ;  $W_C$  is cement dosage per unit volume concrete,  $kg/m^3$ .

The APDL language is as follows:

HE00=72450\*0.69\*DAY\*\*(-0.44)\*exp((-0.69)\*D AY\*\*0.56)

BFE, ALL, HGEN, HE00.

Cement types	$Q_0 / (J \cdot g^{-1})$	a	b
ordinary Portland cement no. 425	330	0.69	0.56
ordinary Portland cement no. 525	350	0.36	0.74
ordinary Portland cement for dam no. 525	270	0.79	0.70
ordinary Portland slag cement for dam no. 425	285	0.29	0.76

### 3.4.3 Other Parameters

The lock floor was poured in July and the project lasted about 20 days. The construction units have adopted a series of cooling measures in the aspect of concrete temperature control, established concrete mixing water cooling system, set up awnings on the mixing floor as well as on all the concrete transport vehicle and set the cold water spray system for concrete curing. Laboratory strictly controlled all sorts of gelled material warehousing temperature and optimized mixing ratio of concrete at the same time, using large dosage of admixture low cement, and effectively reducing the hydration heat of concrete. The average concrete pouring temperature was concluded by the field monitoring data. The average water temperature was 15 °C, concrete mixing aggregate average temperature was 28 °C, the average temperature of river sand was 29 °C, the average temperature in outlet was 29 °C, the average temperature of concrete transportation to the scene was 30 °C and the concrete transportation rise temperature was 1 °C. Therefore, authors defined the concrete pouring average temperature was 32 °C.

After completion of construction, it should set the thermal insulation layer on concrete surface and adopt geotextile coverage with water conservation. The deck of the concrete used double conservation of geotextile and plastic sheeting, lateral and upstream and downstream face used foam board insulation. The heat transfer coefficient of the insulation layer can be calculated as Eq. (4):

$$\beta = 1/\left[\Sigma \delta_i / \lambda_i + 1/\beta_q\right]. \tag{4}$$

where:  $\beta$  is the heat transfer coefficient of concrete surface insulation layer,  $W/(m^2 \cdot k)$ ;  $\delta_i$  is the thickness of the insulation material, m;  $\lambda_i$  is the thermal conductivity of various insulation materials,  $W/(m \cdot k)$ ;  $\beta_q$  is solid heat transfer coefficient in the air, taking 23,  $W/(m^2 \cdot k)$ .

In the actual maintenance, authors use a layer of geotextile and a layer of plastic film with aggregate

 Table 3
 Calculation model parameter table.

Characteristics Concrete		Pedestal rock	
Density/ $(kg \cdot m^{-3})$	2,400	1,900	
Specific heat/ $(J \cdot / (g \cdot ^{\circ}C))$	0.97	0.88	
Thermal conductivity/ $\left(kJ \cdot / \left(m \cdot d \cdot ^{\circ}C\right)\right)$	254.4	289.3	
Poisson's ratio	0.18	0.20	
Elasticity modulus/ GPa	2.8	1.0	

thickness of 5 mm. Authors can calculate that  $\beta = 320KJ/(m^2 \cdot K)$  by the type. And the thickness of foam board is 1.5 cm,  $\beta = 183KJ/(m^2 \cdot K)$  can be calculated.

The material parameters of the rock and soil body and concrete are shown in Table 3.

## 4. Calculation Results and Analysis

# 4.1 Numerical Calculation Results and Field Monitoring Results

Each layer of concrete will be prepared 35 thermometers and numbered from the left to the right bank, upstream to downstream total about 5 rows with 7 of each. The first layer of embedding height was 7.4 m, the second layer was 9.4 m, the third layer was 10.9 m and the fourth layer was 14.0 m. It extracts the daily average temperature compared with the results of numerical analysis. Through transient thermal analysis by ANSYS, authors got ideal results of numerical analysis, and in order to clearly see the concrete internal temperature changes, the lock floor was sliced to get the temperature field cloud picture and temperature time curve of each time and each part.

Fig. 5 is the temperature process diagram of the upstream T1-T7 thermometers on the first layer. The Fig. 5 shows that in a few hours before concrete pouring, the temperature has dropped a little, then the temperature rose faster, peaked after 2-3 days, and later came falling until smooth after 4-5 days. The influence of outside temperatures during this period was not significant for internal temperature change of concrete and the cement hydration heat effect was the main reason for the concrete internal temperature

change. The maximum temperature difference between T4 and T7 was 4.5 °C when T4 thermometer reached 3.5 °C. The Fig. 6 shows that temperature variation curve of four thermometer close to external is the same as that in Fig. 5, peaked around 3-4 days, and 3 thermometer inside concrete reached the maximum about 5-6 days. At this stage, the concrete internal temperature and surface temperature have a larger temperature difference, and the maximum reached 7 °C in 7 days.

Fig. 7 was floor representative parts thermometer T18 compared with the results of numerical analysis. The Fig. 7 shows that the numerical analysis results and the measured results have the same change trend, but the calculation results was slightly larger than

measured values. The reason was that the numerical calculations considering the boundary conditions are less than the actual situation. The maximum error was 6.3% and the minimum error was 1.2%. This shows that the numerical value can reflect the test result, and authors can, according to the numerical analysis, optimize the layered pouring solution.

#### 4.2 Layered Pouring Scheme Optimization

Authors will optimize the original four layer pouring scheme, a total divided the structure into 5 layers for pouring and simplify the original 3.1 m large thickness pouring layer. The first layer was 1.5 m high, the second layer was 1.0 m, the third layer was 1.5 m, the fourth layer was 2.0 m and the fifth layer was 1.5 m.







Fig. 6 The temperature process diagram of T15-T21.





<sup>21.7859</sup> <sub>25.131</sub> <sup>28.4762</sup> <sub>31.8213</sub> <sup>35.1665</sup> <sub>38.5117</sub> <sup>41.8568</sup> <sub>45.202</sub> <sup>48.5471</sup> <sub>51.8923</sub> Fig. 8 The 9th day temperature distribution cloud.



Fig. 9 The 16th day temperature distribution cloud.

After analysis of ANSYS software, authors got the temperature distribution in optimization pouring solution cloud and compared it with the original pouring solution.

Fig. 8 was the temperature distribution cloud of the floor of the ninth day with the comparison of optimization scheme. The Fig. 8 shows that after the layered scheme was optimization, in the same pouring time, the highest temperature of the original fell from 56.32 °C to 51.89 °C, a fall of 4.43 °C, and it well reduced the concrete hydration heat temperature.

Fig. 9 was temperature distribution cloud of the floor of the 16th day with the comparison of optimization scheme. The Fig. 9 shows that after the completion of floor pouring, the highest temperature of concrete was basically identical with optimization scheme. This suggests that structure is as a whole in the same pouring time, and the hydration heat of concrete are basically the same. If you want to reduce the temperature of the floor pouring after the completion of the whole structure, you could choose the method of extend pouring construction clearance of each layer.

## 5. Conclusions

The mass concrete temperature will rise rapidly after pouring by the influence of cement hydration heat. The concrete temperature in the structure table will achieve maximum value after 1-3 days, and the corresponding internal temperature of concrete structure will achieve the maximum after 3-8 days. The maximum temperature value of internal concrete is generally greater than table of concrete.

The lock floor concrete maximum temperature is related to the thickness of the pouring layer, the higher the temperature of the internal concrete with the greater thickness. The thickness of the relatively large layer is 3.1 m and its internal temperature is more than 50 °C, besides that the maximum of the structure is as high as 54.8 °C.

It is related to Slab concrete temperature maximum size and the thickness of the casting layer. The greater the thickness of concrete internal temperature of the concrete is, the greater the value is. Concrete pouring relatively large third layer thickness of concrete pouring is 3.1 m, and the internal temperature of concrete greatly value the storehouse are more than 50 °C, maximum of 54.8 °C. In the early stage of the concrete cooling, cooling rate of the concrete table is larger than the internal and the maximum temperature difference between the internal and table usually occurs at this stage.

According to the above rule of concrete temperature change, it is suggested that taking the following engineering measures to reduce the concrete temperature cracks: (1) taking precooling method to reduce the concrete placing temperature; (2) appropriately extending concrete pouring construction clearance of each layer and decreasing the layer thickness; (3) after the concrete temperature reaches the maximum, appropriately increasing thermal insulation layer of heat preservation measures so as to prevent concrete surface cracks caused by rapid cooling rate.

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