# Optimization of Cooling Pipes Inside Mass Concrete Bridge Pile Cap

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**Abstracts.** The hydration heat of cement always causes large temperature difference between surface and core area of mass concrete at early ages due to its huge volume, which is apt to cause concrete to crack. Cooling water pipes are often installed to carry out part of the mass concrete internal heat, therefore the cracks can be avoided. Based on a railway bridge mass concrete pile caps construction, three key parameters of cooling pipes, which are pipes spacing and flow rate of cooling water as well as pipeline layout are studied by Midas/Civil software in this paper, and an optimized cooling pipes design is proposed.

## 1 Introduction

With a booming economy and rapidly developed construction technology, mass concrete constructions have been widely used in China, especially in the bridge engineering. The hydration heat of cement can cause large temperature difference between surface and core area of mass concrete at early ages due to its huge volume, which is apt to cause temperature cracks, therefore the safety and durability of mass concrete structure are adversely influenced [1]. To reduce the temperature difference, cooling water pipes are often installed, by which part of internal heat is carried out of mass concrete, thus temperature cracks can be avoided, and it has been proven to be an effective way by many mass concrete engineering practice [2]. However, further researches on several key parameters of cooling pipes are still expected. Midas/Civil software is used for study on finite element simulation of cooling pipes parameters optimization of Yiying River Railway Bridge mass concrete pile caps in this paper. The key parameters of cooling pipes including pipes spacing and flow rate of cooling water as well as pipeline layout are analyzed, and an optimized cooling pipes design is proposed too.

## 2 Temperature simulation

### *2.1 Introduction to project*

Yiying River Railway Bridge construction project locates in Yangquan city, Shanxi province, central China. The upper structure of the bridge is a (86+150+86) meters three-span prestressed rigid concrete frame, which is supported by solid thin-wall double limbs piers, and the pile caps at the bottom of the piers are designed as 12.4m×12.2m×4m reinforced concrete structure with continuous pouring C30 pump concrete. Considering their large volume, these pile caps are typical mass concrete structures, and the cooling pipes are designed to be installed inside the pile caps to avoid cracking. The cooling pipes design setting three key parameters, as follows, pipes spacing is 160 cm, flow rate of cooling water is 3.0 $m^3$/h, and the snake style is adopted as the pipeline layout. Φ40mm steel pipes with good thermal conductivity are used, and totally four layers of these steel pipes along the height are built inside the pile caps, as shown in Figure 1. The cooling water cycle starts when the height of concrete poured exceeds the pipes 20 cm, while stops at the seventh day after placing concrete.

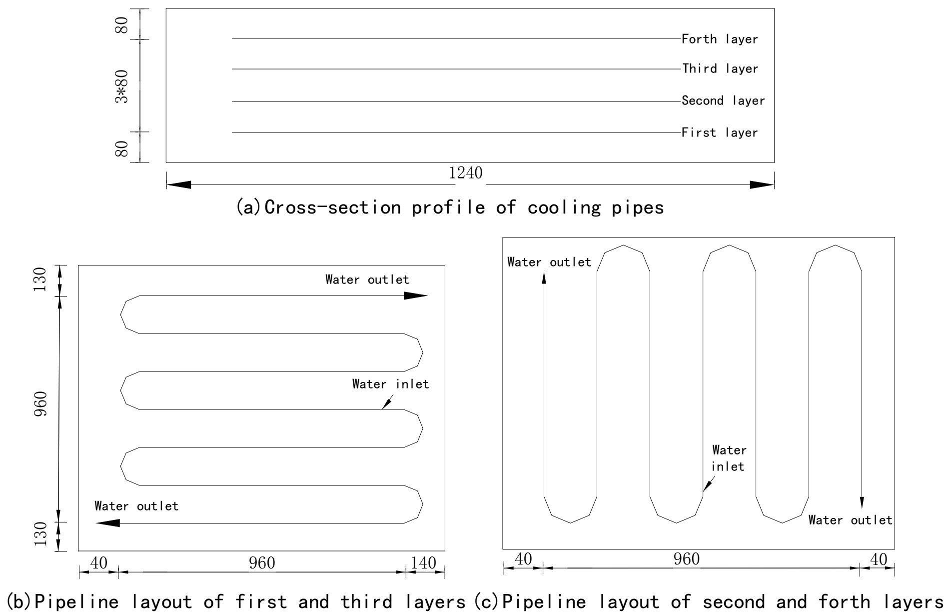



Fig.1. Cooling pipes layout design

## *2.2 Temperature simulation*

### *2.2.1 Basic assumptions*

When Midas/Civil software is used for finite element simulation on cooling pipes, the following basic assumptions are assumed:

1、 Concrete presents a good uniformity, so each finite element node shares the same heat rate.
2、 Concrete from the same layer starts with the same initial temperature.
3、 Concrete surface heat release coefficient is assumed to be constant.
4、 The effects of wind and incidence of the sun are ignored.
5、 The effect of pipes volume is ignored.
6、 The effect of steel bars is ignored.

### *2.2.2 Simulation*

Considering the symmetry of pile caps structure, the 1/4 profile of the structure can be used for analysis. Moreover, with a thorough consideration on construction scheme, material properties, shape and size and other factors, Midas/Civil software is used for temperature control effect simulation of cooling pipes on mass concrete. The relevant parameters of concrete are shown in Table 1, and the important parameters of finite element modeling are shown in Table 2.

Table 1 Relevant parameters of concrete

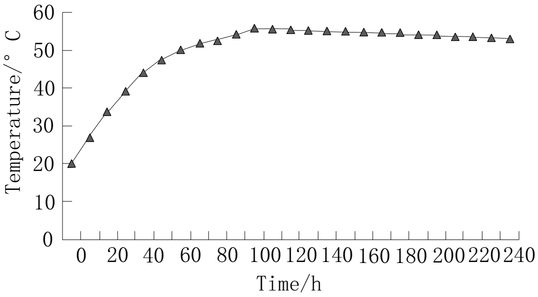
| Materials | Mixture proportion kg/m$^3$ | Percentage % | Molding temperature ℃ | Specific heat kJ /(kg·℃) |
|---|---|---|---|---|
| Fly ash | 141 | 5 | 10 | 0.45 |
| Cement | 269 | 11 | 40 | 0.4 |
| Fine aggregate | 772 | 32 | 7 | 0.69 |
| Coarse aggregate | 1062 | 44 | 7 | 0.71 |
| Water | 157 | 6 | 7 | 4.18 |
| Admixture | 3.51 | 0.2 | 7 | 4.19 |

Table 2 Important parameters of finite element modeling

| Parameters | Values |
|---|---|
| Thermal conductivity coefficient of concrete | 8.916kJ /(m·h·℃) |
| Specific heat of concrete | 0.897kJ /(kg·℃) |
| Molding temperature of concrete | 11.3℃ |
| Maximum adiabatic temperature | 58.56℃ |
| Heat release coefficient of concrete | 63.19kJ /($m^2$·h·℃) |
| Boundary temperature of foundation | 10℃ |
| Ambient temperature | 20℃ |
| Diameter | 0.04m |
| Input temperature | 26～30℃ |
| Output temperature | 32～34℃ |
| Flow rate | 3.0$m^3$/h |

*2.2.3 Simulation results*

The highest temperature always appears at the core area of mass concrete structure [3], so the central point of second cooling pipe layer is selected as the highest temperature location for simulation, and its temperature-time simulation curve is shown in Figure 2. This simulation result considers only the temperature reducing effect of cooling pipes, other factors are not involved in this study.



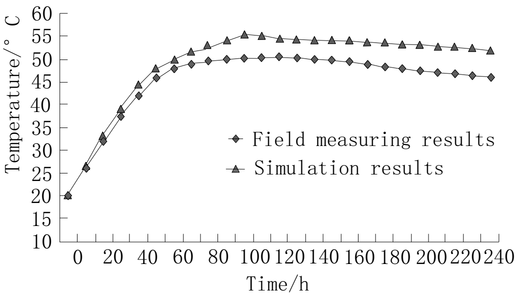




Fig.2. Temperature-time simulation results Fig.3. Comparison of field measuring results and simulation results

In order to verify the accuracy of finite element simulation results, the simulation results are compared with the field measuring results of second layer central point, as shown in Figure 3.

As shown in Figure 3, the simulation values are slightly higher than the measured ones, and temperature peaks from both curves appear very close, also the temperature trends over time are similar too. By comparison, finite element simulation results have satisfied precision on predicting the internal temperature change of mass concrete, therefore the simulation results can be used effectively for the optimization of mass concrete construction scheme and benefit field practice.

## 3 Key parameters optimization

### *3.1 Pipes spacing*

According to the original design of cooling pipes, the snake style arrangement with the pipes horizontal spacing of 160cm steel pipes is installed inside the pile caps. In order to study one of the cooling pipes key parameters, which is pipes spacing's effect on temperature control exclusively, other parameters remain unchanged according to the original design, while the pipes spacing are set at 120 cm and 200 cm to build two new finite element models respectively. Cooling pipes model with spacing of 120cm is shown in Figure4, and cooling pipes model with spacing of 200cm is shown in Figure 5.

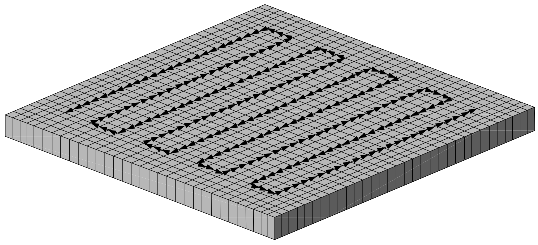


Fig.4. Cooling pipes model with spacing of 120 cm

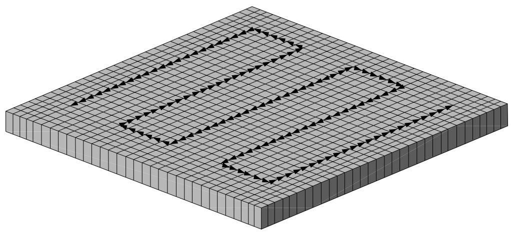


Fig.5. Cooling pipes model with spacing of 200 cm

In order to comparatively analyze the temperature control effects of the three pipes spacing models, the central points of second cooling pipes layer from each pipe spacing patterns are selected for modeling, and three temperature-time simulation curves are shown in Figure6.

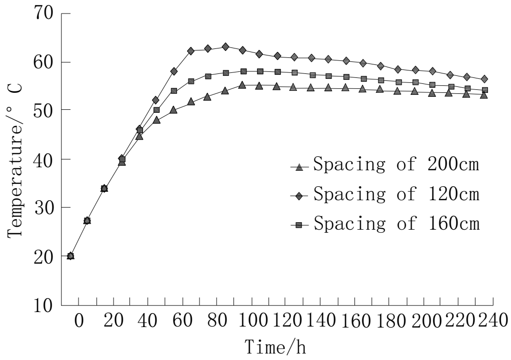



Fig.6. Three different cooling pipes spacing simulation results

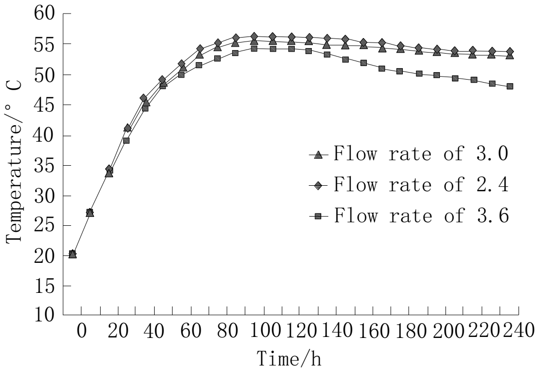



Fig.7. Three different flow rates simulation results

As shown in Figure 6, the temperature trends over time of all the three pipes spacing patterns are almost the same. The temperature all mount rapidly at the beginning, then decrease slowly, finally reach a steady state. Among them, the temperature of pipe spacing of 120 cm presents the lowest. The temperature peak is just 53℃, and the temperature reaches a steady state after falling to 51℃, so the pipes spacing of 120 cm performs the best temperature-reducing effect, whereas the temperature peak reaches as high as 65℃ at the pipe spacing of 200 cm, which performs the worst of all the three spacing. Therefore 120 cm could be considered as the best pipes spacing on temperature reducing effect. This simulation results are easily understandable for the smaller the pipes spacing is, the longer route the cooling water has to take inside mass concrete, then more internal heat could be carried outward.

### *3.2 Flow rate*

According to the original design of cooling pipes, the flow rate of cooling water is 3.0 $m^3$/h. In order to study one of the cooling pipes key parameters, which is flow rate of cooling water's effect on temperature control exclusively, other parameters remain unchanged according to the original design, while the flow rate are set at 2.4 $m^3$/h and 3.6 $m^3$/h to build two new finite element models respectively, and the temperature-time curves of different flow rate are shown in Figure 7.

As shown in Figure 7, the temperature trends over time of all the three flow rate patterns are almost the same. The temperature all mount rapidly at the beginning, then decrease slowly, finally reach a steady state. Among them, the temperature at flow rate of 3.6 $m^3$/h presents the lowest. The temperature peak is just 56℃, and the temperature reaches a steady state after falling to 48℃, whereas the temperature of the rest two flow rate patterns presents almost the same, showing comparatively higher temperature than the flow rate at 3.6 $m^3$/h. Therefore 3.6 $m^3$/h could be considered as the best flow rate of cooling water on temperature reducing effect.

Laminar flow and turbulent flow are two patterns of cooling water's flow inside the pipes, and turbulent flow absorbs more heat from surrounding concrete than laminar flow does. Cooling water flows as the laminar flow pattern when the flow rate is low, only when the flow rate is greater than the critical velocity, turbulent flow will happen. In this study, the flow rate of 3.6 $m^3/h$ has already passed the critical velocity, whereas the rest two flow rates haven't, so the flow rate of 3.6 $m^3/h$ performs the best on temperature reducing.

### *3.3 Pipeline layout*

According to the original design of cooling pipes, the snake style is adopted as the pipeline layout, as shown in Figure8. In order to study one of the cooling pipes key parameters, which is pipeline layout's effect on temperature control exclusively, other parameters remain unchanged according to the original design, two brand new pipeline layout patterns are introduced to build two new finite element models respectively, which are circle style and 1/4 independent snake style. Cooling pipes model with circle style layout is shown in Figure9, cooling pipes model with1/4 independent snake style layout is shown in Figure10. and all the temperature-time curves of the three different pipeline layout are shown in Figure 11.

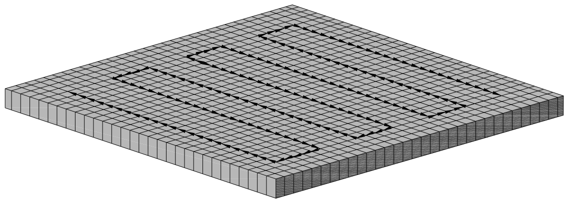


Fig.8. Snake style pipeline layout

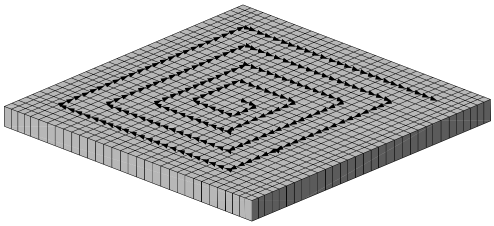


Fig.9. Circle style pipeline layout

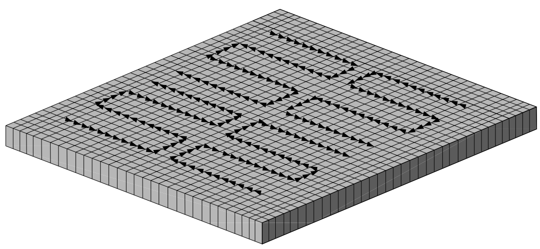


Fig.10. 1/4 independent style pipeline layout

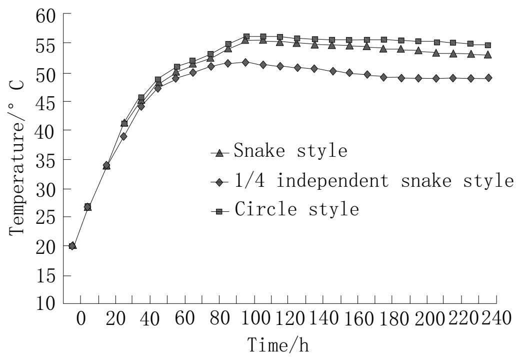



Fig.11. Three different pipeline layout simulation results

As shown in Figure 11, the temperature trends over time of all the three pipeline layout patterns are almost the same. The temperature all mount rapidly at the beginning, then decrease slowly, finally reach a steady state. Among them, the temperature of 1/4 independent snake style pipeline layout presents the lowest. The temperature peak is just 51℃, and the temperature reaches a steady state after falling to 47℃, whereas the temperature of the rest two pipeline layout patterns presents almost the same, showing comparatively higher temperature than the 1/4 independent snake style. Therefore 1/4 independent snake style could be considered as the best pipeline layout on temperature reducing effect.

The main reason for this simulation results is that the 1/4 independent snake style layout allows the cooling water flows longer time in the core area of mass concrete than the rest two patterns, thus more concrete internal heat will be absorbed by cooling water.

### *3.4 Design optimization*

As discussed above, pipes spacing of 120 cm, and the flow rate at 3.6 $m^3/h$, as well as the 1/4 independent snake style pipeline layout are three optimized key parameters for cooling pipes. If all these three optimized parameters are adopted in the cooling pipes design, an optimum mass concrete temperature reducing effect will be accomplished. To prove this argument, three optimized key parameters presented above are all adopted to build a new finite element model, and the simulation results of the optimized parameters comparing with the results of the original design are shown in Figure 12.

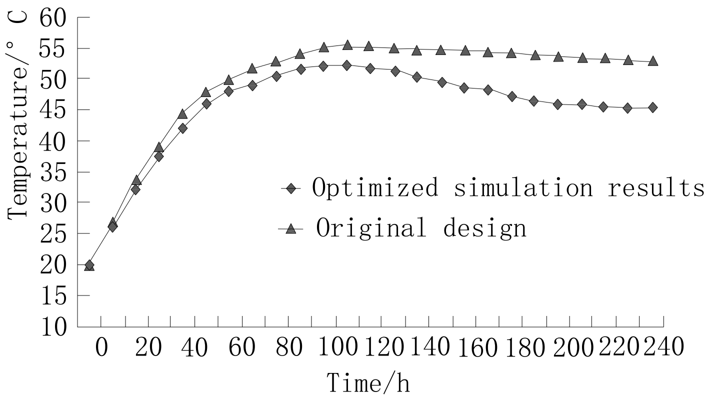



Fig.12. Comparison of optimized simulation results and original design

As shown in Figure 12, the temperature trends over time from both curves are almost the same. The temperature all mount rapidly at the beginning, then decrease slowly, finally reach a steady state. The temperature peak of the optimized parameters model is just 48℃, 4℃ is declined comparing to the original design, and the temperature reaches a steady state after falling to 46℃, 5℃ is declined comparing to the original design, so we can draw a conclusion that with these three optimized key parameters, cooling pipes presents a better temperature reducing effect.

## 4 Conclusions

By the key parameters simulation of the cooling pipes inside Yiying River Railway Bridge mass concrete pile caps, pipes spacing and flow rate as well as pipeline layout are optimized in this paper, and an optimized cooling pipes design is proposed.

The accuracy of finite element simulation on mass concrete is proved, and the simulation results provides a valuable reference for some similar mass concrete constructions in the future.

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