Review on the Numerical Simulation Methods of Cooling Pipe in Mass Concrete

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Abstract. In early twentieth Century, with a large number of applications of concrete in hydraulic structures, concrete crack has gradually attracted people's attention. Most scholars think, the cause of crack in hydraulic concrete is mainly because temperature stress. Proved by engineering examples, cooling pipe has become an indispensable construction technology to reduce temperature stress and cracks in mass concrete. Some typical cooling pipe algorithms, including the equivalent algorithm, theoretical analysis and finite element combined method, the discrete model of cooling pipe, embedded element method, substructure method, composite element method are discussed and compared. Based on this, an improved algorithm, which may better solve the contradiction between computational accuracy and efficiency, is indicated to be the future research content.

Introduction

In early 1930s, USA Bureau of reclamation studied an artificial cooling method in the design of Hoover gravity arch dam and proved by experiment pipe cooling is an effective measure, then the method has been popularized. At present, pipe cooling has become a very important measure of temperature control. In order to obtain more accurate calculation method of the effect of pipe cooling, a large number of related researches have been done at home and abroad.

With the development of the simulation algorithm and continuing research on essence of things, the rationality of simulation calculation and accuracy of the results are also improved and the calculated result is gradually accepted by engineering field, which has become an important basis for decision-making, design in engineering. As a mature simulation method, finite element method has played a huge role in temperature control and crack resistance of mass concrete and the calculated results have also become an important basis for all kinds of temperature control scheme and measures. In the study of finite element algorithm to simulate various temperature control measures, pipe cooling temperature field of concrete has always been a hotpot and difficulty. The cooling pipe algorithms in the engineering currently mainly are: the equivalent algorithm, theoretical analysis and finite element combined method, the discrete model of cooling pipe, embedded element method, substructure method, composite element method. This paper will discuss and compare these methods in detail.

Several Typical Simulation Methods of Pipe Cooling and the Advantages and Disadvantages:

Equivalent Algorithm of Pipe Cooling Temperature Field

The cooling pipe equivalent algorithm was first proposed by academician Zhu Bofang and the main principle is that the cooling effect of pipe is equivalent to computational domain of the structure. By modifying the heat conduction equation and using finite element method to solve the modified heat conduction equation, we can obtain the temperature field of the concrete that consider the effect of pipe cooling [1, 2].

Advantages: The cooling pipe is no need to discrete into finite element, so there is no need to discrete concrete which has a great temperature gradient around pipe into finite element. The element quantity is less, thus, people can simulate a large structure with a smaller computing scale.

Disadvantages: The method cannot simulate the actual effect of pipe cooling in different position and the gradient of cooling pipe. Fine simulation for thin-walled structure is different with the reality. In addition, some parameters of this method are fuzzy and not easy to grasp.

Theoretical Analysis and Finite Element Combined Method

Professor Mai Jiaxuan combine the analytical method of the cooling pipe and the finite element method, using the pipe analytical method in the concrete within a certain range and using finite element method at the boundary[3]. The whole process of calculation of temperature and stress will use ordinary finite element method. Only when there is cooling water, add the theory solution of calculation. In addition, Zhu Zhenyang and others, Hohai University, put forward a new calculation method (semi analytical finite element iterative approximation method) according to the characteristics of the temperature gradient around pipe. Even if number of nodes is less, we also can accurately calculate the temperature field around the pipe and water temperature along the pipe [4].

Advantages: There is no need to divide the places around the pipe into small elements, there is no element transformation problem, so the scale of calculation is small and the method is simple and easy to master.

Disadvantages: It is not easy to correctly reflect the effect of pipe cooling. The local effect of temperature change cannot be considered, particularly, not being able to simulate the temperature field around the cooling pipe and the situations around the cooling pipe often have great influence to determine pipe layer spacing and pipe spacing, flow velocity, water temperature and cooling days of watering. So this method cannot simulate the actual situation very truly.

The Discrete Model of Cooling Pipe and Its Pretreatment Method

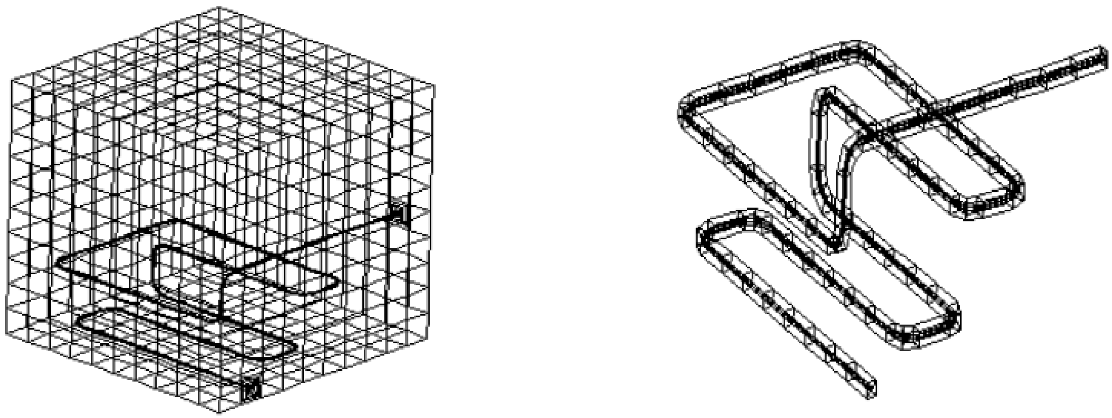

Fig. 1 The Discrete Model of Cooling Pipe

On the basis of previous researches, Professor Zhu Yueming proposed the discrete model of cooling pipe, which can accurately simulate the cooling pipe. When use the algorithm to calculate the temperature field of concrete which contains cooling pipe, pipe can be split out as realistic as possible[5]. Therefore, this method requires a second subdivision to the existing finite element model, directly spill out pipe boundary and discrete concrete around pipe which has a high temperature gradient into finite element.

Advantages: The algorithm can finely simulate the most factors that objectively exist in process of pipe cooling, such as pipe spacing, pipe location and form, flow velocity, flow direction, inlet water temperature, temperature changes along the pipe, the pipe material and the thickness of pipe wall, length of pipe etc.

Disadvantages: While preprocessing procedure changed pipe element, it also makes change to the many surrounding elements and the scope of influence is very big. There will be a lot more elements than the original grid, which is not very convenient in using, especially for pump station and other complex structure and people often cannot apply pipe element to the whole grid. The scale of grid of big project that add pipe is too large, may not be operational in common computer.

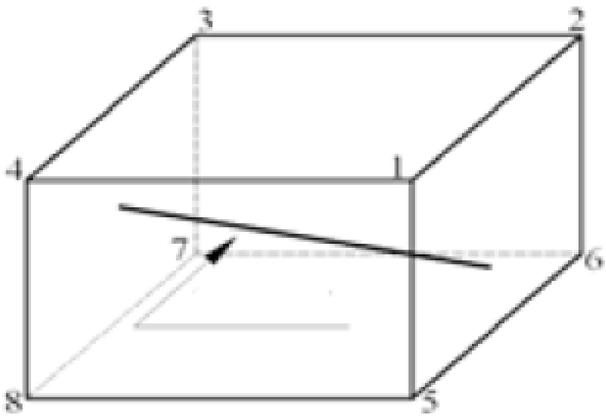

Fig. 2 Embedded Element

Embedded Element Method of Pipe Cooling Temperature Field

Pipe embedded element method was first proposed by Professor Chen Guorong and the main principle of this method is: considering the element that pipe comes through as embedded element, considering the "pipe" in the element as a "virtual pipe boundary" in the process of calculation[6].

Advantages: There is no need a second subdivision to the original grid, so comparative analysis of the modeling scheme in the early stage will not be affected by the second subdivision. Thus greatly reduce the amount of computation and improve the computational efficiency of pipe cooling temperature field.

Disadvantages: If there is a need to accurately consider the temperature field around the pipe, to reflect the actual situation the dense grid is still needed, in addition, the change of water temperature along the pipe has not yet been considered.

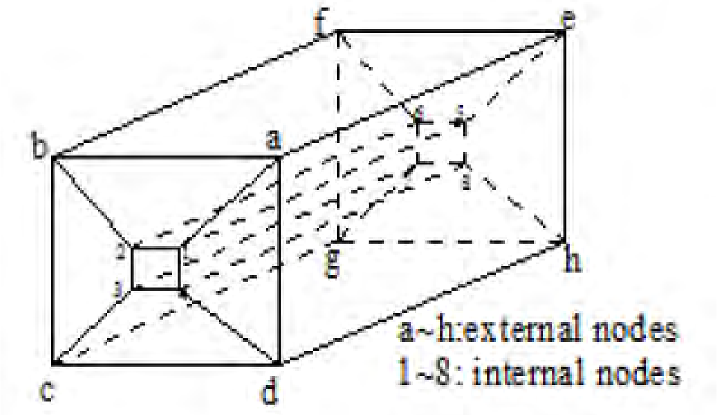

Fig. 3 Substructure of Pipe

Substructure Method of Cooling Pipe

This method was first proposed by Professor Liu Ning and the basic idea is: in order to reduce the increase of computation scale caused by a second subdivision. With substructure theory, which considers pipe and elements around the pipe as a substructure super-element, we can condense the internal node element and then synthesize the whole equation in the process of calculation. Thereby reducing the number of integral equations and improving the efficiency of equation solving [7]. After getting temperature value of external node, then use the process of “condensation" to obtained "intermediate data", in the way, we can calculate the node temperature value through "backward" operation.

Advantages: When the model size is not too great, the computational efficiency is significantly improved, which can improve the calculation scale and solving efficiency.

Disadvantages: When the model size is further increased, the acceleration effect will be increasingly not obvious. In addition, substructure algorithm also need to discrete pipe, the basic model (without cooling pipe model) element configuration has a higher requirement (generally hexahedral and tetrahedral elements), which will increase the difficulty of preprocessing.

Composite Element Method

Composite element method assumes that there are a plenty of areas with different material properties inside of an element. There are clear boundaries between regions: such as the fissures and bolt of the rock, pipe wall in concrete that contains a cooling pipe. We define the areas with different material properties as different sub-element, the sub-element can be in various shapes, not necessarily standard finite element. The whole element is defined as a composite element. Grid that composite element used is similar with conventional finite element method, but element distribution and size in the grids are determined by the body of structure and the gradient of physical quantity, not too much to consider of the interface problems of discontinuous medium [8,11]. Li Guiliang made an improvement on the foundation of the method and program of Wu Shiyong and Deng Jianqiang, changing the processing methods on the pipe turning element and try to avoid generating redundant dividing line on the two surface of the turning element, which can reduce the calculation error of the subsequent calculating program [12]. Wu Chao and others, Hohai University, deduced the composite element control equations on the basis of previous studies by using the variational principle and programmed preprocessing procedures for composite element with cooling pipe, verified the program by example.

Advantages: The workload to establish preprocessing model is less, difficulty is lower and easy to realize. In the process of calculation, the composite element can adjust to be ordinary finite element according to specific circumstances, such as when to stop the cooling water and so on. Composite element is based on finite element, the program editing can well integrate into the existing finite element program, without the need to edit the overall solution program separately.

Disadvantages: At present, computing in turning and multiple pipes is still in the research stage. The visualization of post processing needs further improvement.

Conclusion

Due to the mass concrete containing the cooling pipe is a complicated 3D unstable temperature field, there are many problems which need to be considered. The common used cooling pipe algorithms in engineering are: the equivalent algorithm, theoretical analysis and finite element combined method, the discrete model of cooling pipe, embedded element method, substructure method, composite element method .But they have not completely solved the contradictions between calculation accuracy and efficiency. Due to the time for the composite element method for cooling pipe research and application is relatively short, the calculation of the composite element is still in the research stage and the visualization of post processing is not perfect. Therefore, further study on simulation of cooling pipe, in order to meet the calculation accuracy and efficiency requirements which can guide the engineering practice, has practical meaning and value.

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