Fire Safety of Integrated Pipeline Corridor Cable Block Based on Numerical Simulation

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Abstract. The comprehensive pipe gallery is a tunnel space built underground in the city, which can centrally lay all kinds of municipal pipes in the tunnel for unified management, which can not only protect the pipes, but also improve the land utilization rate. However, with the increasing of integrated pipe gallery construction and pipeline inclusion, various safety accidents have appeared, among which the fire risk of cable cabin is the greatest. This paper mainly studies the fire safety of cable cabins of integrated pipe gallery based on numerical simulation. In this paper, PyroSim fire software was used to simulate the fire accident in construction. Through the investigation of the construction site, simulation parameters were set to simulate the fire situation in a real and objective way. The temperature, smoke and visibility changes under different working conditions were studied by setting several groups of thermocouples, smoke sensing points and visibility slices.

Key words: Numerical Simulation, Integrated Pipe Gallery, Cable Compartment, Fire Simulation

1. Introduction

Comprehensive pipe gallery project is to gather communication, electric power, heat, gas, water supply, drainage and other municipal public pipelines in a tunnel space built underground in roads or factory areas. At the same time, special access ports, feeding ports, vents and monitoring systems are set up to implement unified planning, design, construction and management [1]. Comprehensive pipe gallery is an advanced model of municipal infrastructure construction, and it is also necessary to build a new modern city. Our country has entered the new era of development, urban economy, science and technology, culture and people's living standard is increasing day by day, the underground pipeline will be needed to increase, the current urban underground is more and more disorderly, thick as a spider's web of pipeline in the competition for the limited underground resources, allowing the development of underground space is so disorderly, to the urban development brings the problems [2]. Based on this situation, the construction of underground comprehensive pipe gallery becomes particularly important. Compared with the intricate aboveground pipelines, the comprehensive pipeline corridor has its natural advantages: the feeding ports, vents, access ports and personnel escape ports of the comprehensive pipeline corridor are set in harmony with the natural environment on the
green belt of the road, improving the situation of overhead pipelines everywhere, and the urban environment becomes more beautiful [3]. At the same time, it also saves urban land and makes its urban planning more reasonable. To a large extent, the inspection and maintenance of various pipelines on the road are reduced, and the traffic is maintained smoothly, and the road safety performance is greatly improved. The comprehensive pipe gallery is equipped with a perfect monitoring system, such as safety risks can be eliminated in time, conducive to pipeline maintenance and management. It reduces the security risk of the city and improves the stability of the safe operation of the city to a certain extent [4].

In terms of the development time of underground comprehensive pipe gallery, the development of foreign countries should be more than 100 years in advance. The first comprehensive pipe gallery was built in Paris, France, and then ushered in the stage of vigorous development. At present, Japan, Singapore and other countries to develop the technology of underground comprehensive pipe gallery has been very perfect. In terms of the use function of the underground comprehensive pipe gallery, some foreign countries with very mature laying technology have incorporated sewage pipes and garbage pipes into the pipe gallery [5]. However, the laying of these two kinds of pipelines has not been tried out in China, and traditional gas pipelines, power and telecommunication pipelines are mainly installed in the corridors. Therefore, the study on the use function of underground comprehensive pipe corridors in China needs to be further strengthened [6].

The research of this paper is conducive to the optimization of the fire extinguishing scheme of the pipe gallery, can provide reference for the selection and design of the fire extinguishing system suitable for the urban underground comprehensive pipe gallery, and provide protection for the safety of people's lives and property.

2. Numerical Simulation of Fire Control in Comprehensive Management Cable Plant

2.1. Fire Model Selection
Combustion is an extremely complex process, which includes a series of physical and chemical changes, and researchers have done a lot of research on fire combustion. At the beginning of the study, people only through a large amount of data, summarizes the statistical law of fire to draw fire burning process, large work volume on the method, process and there is no universal, so more and more scholars began to focus on fire simulation, and a variety of model is established to describe the complex process of fire, among them, the area model and field model are commonly used in tunnel fire.

The core of the regional model is to divide the object to be studied into different regions, and assume that the parameters in each region, such as temperature and pressure, are uniform. In each region, the conservation of mass, momentum and energy are used to describe the fire process. This model is relatively simple and can contain multiple phenomena in one area without making the process too complicated and running fast. However, due to its strong dependence on existing data, this model is very sensitive to changes in parameters, and small changes in parameters can easily lead to huge calculation errors. Moreover, in some cases, The spatial distribution of various parameters in the region cannot be truly stratified and uniform, the model loses the premise and foundation, and the accuracy of the calculation results will inevitably be greatly affected, so its application scope is limited [7-8].

The field model is to divide the research object into tens of thousands of grid units. According to the conservation of mass, momentum, energy and the law of chemical reaction, etc., the theoretical model of fire process is formed into a closed set of equations, and these equations are solved in each grid unit to describe the fire process [9]. The model can provide detailed information of the fire process, and compared with the research object with more complex internal structure, the field simulation can calculate the fire process more accurately. With the continuous development of computer technology, the limitation of using field model to calculate has become smaller and smaller, so it has been more and more widely used by scholars around the world.
2.2. PyroSim Software Introduction
Pyrosim is a software developed by NIST (National Institute of Standards and Technology), which is specially used for fire simulation. It can accurately predict smoke spread and fire temperature changes based on the theoretical basis of fluid mechanics. It solves modeling problems such as heavy workload and error-prone FDS parameter setting. It can not only modify and view the model, but also visually see smoke flow, internal temperature change and visibility in a fire by setting monitoring points [10]. Pyrosim can simulate building fire, electrical fire and other fires by setting parameters such as boundary conditions, size and location of fire source, burning materials, etc. In addition, it has good compatibility and can be directly imported into FDS and DXF format files. Pyrosim is widely used in performance design of building fire prevention, fire science research, fire fighting and alarm system research, fire accident investigation and other aspects. Pyrosim can be used to study changes in smoke, temperature and visibility through fire simulation and propose improvement measures to ensure the safety of personnel and buildings. The safety performance of buildings can also be predicted in the design stage [11-12].

Pyrosim is a fluid dynamics simulation software based on finite element method, which mainly takes fluid movement in fire as the simulation object. The software is based on large eddy simulation, which uses the Navier-Stokes equations with low Mach number to calculate the process of flue gas movement and heat transfer.

2.3. Combustion Model and the Simulation Process

2.3.1. Combustion model
In PyroSim, two combustion models, finite reaction rate model and mixed fraction model, are commonly used to accurately describe the combustion process of fire.

The finite reaction rate model is suitable for the direct numerical simulation method, which is mainly used to simulate the toxic and harmful pollutants produced in the combustion of materials.

For general hydrocarbons, the combustion reaction formula is:

\[ v_{C_xH_y} + v_{O_2} \rightarrow v_{CO_2} + v_{H_2O} \]

(1)

Meanwhile, the chemical reaction rate can be expressed as:

\[ \frac{d\left[C_xH_y\right]}{dt} = -B\left[C_xH_y\right]\left[O_2\right]^{0.5} \cdot \frac{E}{RT} \]

(2)

Where, B is the pre-exponential factor of activation energy of combustion reaction; E is the activation energy of combustion reaction; A and B are the order of magnitude.

In general, the FDS software only under certain conditions can call limited combustion rate model, the model requires a very fine grid and require activation energy E is a constant and independent of the temperature, for a massive fire research in the application of the model and can not get the desired results, therefore, in the latest PyroSim software is no longer using this model, instead, a hybrid combustion model is used as the basis for calculation.

Pyrosim The default combustion model in the fire simulation software Pyrosim is the mixed fractional model, which is suitable for the large eddy model method. In the simulation, the percentage of each component in the mixed gas of various components is set to accurately simulate the real situation. In the burning area, the unburned gas coexists with the new gas that has been burned, which is expressed by the equation Z (x, t) according to the function relationship between space and time where the mixed gas is located. In general, combustibles mixed with air will not burn completely, that is, the assumption of mixing control does not exist in general. During combustion, incomplete combustion occurs because there is not enough air.

2.3.2. Simulation process
When using PyroSim to simulate a fire, pre-processing of simulation is required firstly. Boundary conditions such as model size, mesh size, combustion reaction, fire source parameters and other
parameters are required to be set, as well as devices and slices to be measured, etc., and finally, simulation time is set for output control. After the simulation, PyroSim can output a variety of data results, and the change rules of data can be observed intuitively by using relevant software such as Origin and Excel to process the data. Moreover, PyroSim can directly see the temperature change, smoke concentration change and the spread and diffusion process through Smokeview, so as to accurately obtain the development of fire. In the process of fire simulation, PyroSim can be divided into the following three stages.

Pre-processing stage of simulation: Input boundary conditions such as physical size, mesh division and fire source parameters of the model before modeling, and the setting of these values will serve as the basis of numerical simulation calculation.

The stage of simulation and numerical solution: read in the parameters such as geometric size of the established model and solve them by numerical method, and finally output the calculated results, which is also the core stage of PyroSim's numerical simulation calculation.

Simulation post-processing stage: the obtained output results are presented in the form of dynamic scene by Smokeview program.

3. Simulation Experiment Setup

3.1. Fire Source Setting
The power of fire source is an important factor affecting the scale of fire, and it is also the basis of fire research. At present, in China, according to the power of fire source, fires can be divided into three types: small fire --3 MW, medium fire --20 MW, large fire --50 MW. In the cable cabin, the combustible material is mainly cable, and the space of the tube gallery is narrow, and the burning scale is not large, so it is considered as a small fire. According to the most unfavorable situation, the power of the fire source is 3 MW, and the fire source is located at 100 m in the middle of the second column.

3.2. Cable Settings
Most of the insulation layer and filler of the cable is combustible material, such as rubber, plastic and so on. If it encounters open fire or high temperature, it is easy to burn, especially the PVC plastic cable. When the temperature rises to 390°C, the PVC plastic will decompose and burn. According to the national standard "Power Engineering Cable Design Code" (GB50217-2007) in the commonly used cable insulation material type, this paper uses PVC cable.

3.3. Other Parameter Settings
In order to facilitate the analysis of the changes in the temperature and density of flue gas in the cable cabin, a section is set on the middle longitudinal section to monitor the changes in the volume of flue gas and the size of the wind speed. A thermocouple is set every 0.5 meters along the height direction and every 10 meters along the length direction to obtain the specific temperature and flue gas density value. Referring to the relevant information, in order to prevent the fire from reburning, mechanical ventilation can be carried out only after the fire is extinguished for 0.5h.

4. Simulation Experiment Results

4.1. Temperature Change Process

| T1  |  50 | 100 | 200 | 300 | 400 |
|-----|-----|-----|-----|-----|-----|
| T2  |  78 | 104 | 211 | 349 | 506 |
| T3  |  0  |  21 |  83 |  97 | 165 |
| T4  |  52 |  75 | 119 | 181 | 451 |
| T5  |  0  |  49 |  98 | 142 | 264 |
As shown in Table 1 and Figure 1, the fire source at the middle and bottom is located in the middle of the fire division of the underground integrated pipe gallery, and the two sides are symmetrically distributed. Therefore, in order to study the temperature changes at different positions in the power cabin, the monitoring data of thermocouple T1-T5 and T1 '-T5' on the left side of the fire source are used to plot. According to the temperature change at the height of 3.6m on the top of the power cabin, it can be seen that the temperature at the top of the fire source rises the fastest. As time goes on, the temperature rises at different positions and reaches the peak temperature at about 400s.

4.2. Flue Gas Content Analysis

As shown in Figure 2, the smoke detector S1 '-S5' is located at the characteristic height of human body of 1.5m. The smoke reaches the top above the fire source first, and then spreads to both sides at the top. After it spreads to the end of the fire zone, the smoke backflow occurs. Due to the phenomenon of flue gas backflow, the flue gas concentration at both ends rises faster than that at the middle part. As the combustion proceeds, the flue gas concentration in the middle reaches the peak value first. Because the smoke detector S1 'is located at the left end of the escape port, the smoke
diffuses along the escape port, resulting in a relatively slow rise in the smoke concentration. At about 300s, the flue gas concentration reaches 100%, and the flue gas has filled the whole power cabin, threatening the life safety of personnel.

5. Conclusions
Current underground comprehensive utility tunnel construction rapid development, but our country comprehensive utility tunnel technology is still in its infancy, construction and research of its fire safety studies also show in front of us, the comprehensive utility tunnel in the operation of the biggest security hidden danger for the cable compartment, so in this paper a comprehensive utility tunnel cable compartment fire security to carry out the research. In this paper, PyroSim fire software was used to simulate the fire accident with the highest risk in construction. Through the investigation of the construction site, simulation parameters were set to simulate the fire situation in a real and objective way. By setting several groups of thermocouples, smoke detectors and other monitoring points and visibility slices, the changes of temperature, smoke and visibility under fire conditions were studied. Due to the limitation of experimental conditions, this paper only carried out simulation research. Although the model setting was required to be as close as possible to the actual situation in the simulation process, there was still a certain gap.

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