Numerical Simulation Research on Cable Fire of Urban Underground Comprehensive Pipe Gallery Using Suffocating Fire Extinguishing Method

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Abstract. The integrated pipe corridor cable is the lifeblood of urban power transmission and has a high fire hazard. Once a fire breaks out, the electricity supply of the entire city will be paralyzed. Aiming at the cable fire in the urban underground integrated pipe gallery and combining with the Pyrosim software, this paper adopts the method of fire suffocation, to study the changes of fire smoke in the pipe gallery. The results show that in the pipe gallery of the 200m fire compartment, the open flame can be completely extinguished in 264s under the simulated working condition of the fire source power of 1MW. At 300s after the cable fire, the temperature in the pipe gallery basically maintained a stable state of 40°C. After the fire broke out, the O₂ concentration dropped rapidly and plunged to 16% within 195s and it was completely consumed in 515s. Studies have shown that the use of suffocation to extinguish fires produces less fire smoke in the pipe gallery, and the visibility can be well maintained above 30m.

1. Introduction
In recent years, with the rapid development of urbanization, urban underground comprehensive pipe corridors have been rapidly constructed. As the main line of urban power transmission, the cable transmission voltage of urban underground comprehensive pipe corridors is generally low voltage 6KV~35KV, high voltage 110KV~220KV[1]. However, once the cable is short-circuited, a large amount of heat will accumulate in a short time and cause a cable fire. If the cable cabin cannot be extinguished in time, the city's power supply system will be paralyzed for a long time and cause huge property losses.

Domestic research on integrated pipe gallery fires was not enough. Domestic Huang Ping et al. [2] studied the effect of water mist on integrated pipe gallery cable fires and found that the length of the fired cable mainly increases with the increase in the distance between the nozzles and the horizontal distance between the cables. However, Yang Lizhong [3] investigated the fire protection standards of urban comprehensive pipe corridors and the literature review of fires, and found that the existing fire protection standards of comprehensive pipe corridors in my country are lacking. Liu Xin et al. [5] studied the fire behavior of the underground integrated pipe gallery cable cabin under low oxygen conditions and found that the burning rate decreases under low oxygen concentration, and the flame
area decreases and the degree of flame bending decreases. Jia Boyan et al. [4] studied the fire protection separation and smoke exhaust measures of the underground comprehensive pipe gallery on the fire spread behavior of the comprehensive pipe gallery. Qi has an obvious hindering effect. Researchers like KaiLiang [6] obtained the accuracy of FDS in simulating pipe gallery fires by studying the law of fire spread and smoke distribution in the T-shaped integrated pipe gallery. PufanWang [7] studied the flue gas return of the integrated pipe gallery and found the shape of the flue gas plume is mainly affected by the environmental wind effect and the concave-convex characteristics. Xuemei Wang [8] studied the simulation of the small hole natural gas leakage and diffusion process of the integrated pipe gallery, and found that the frequency of the gallery ventilation is relevant to pipeline pressure and the size of the pipe gallery natural gas leaking.

Although predecessors have done many researches on cable fires in integrated pipe corridors, they mainly focused on setting up smoke-blocking walls and other fire-fighting facilities. There are few studies on flame burning time and smoke distribution in cable cabin suffocation fire-fighting methods.

This article mainly adopts the method of suffocation to extinguish fires to study the flame burning time and the distribution of fire smoke and temperature in the pipe gallery when a fire occurs in the cable cabin of the integrated pipe gallery, and provide a research basis for when to enter the integrated pipe gallery for maintenance in the later stage of the fire.

2 Model establishment

2.1 Model parameter setting

This article mainly uses a fire fluid dynamics software FDS (Fire Dynamics Simulator) developed by the National Institute of Standards and Technology (NIST). The accuracy of this software in the fire simulation of the integrated pipe gallery has been tested by predecessors. [1][2], this paper mainly uses the software to model the original size of some integrated pipe gallery segments in Tianci Road, Jiangning District, Nanjing. The width of the pipe gallery is 2.8m, and the height of the pipe gallery is 2.9m. The length of the cable is 200m, and the fire source power of the cable fire of the integrated pipe gallery is 1MW by consulting related information [9]. The cable geometric cabin model of the integrated pipe gallery is shown in Figure 1.

![Figure 1. Geometric model of the cable compartment](image)

3 Setting of simulation conditions

The "Technical Specifications for Urban Comprehensive Pipe Gallery Engineering" (GB 50838-2015) stipulates the calculation method of the ventilation frequency and the ventilation volume of the pipe gallery. That is, the ventilation frequency of the pipe gallery shall not be less than 2 times/h, and the ventilation change after the accident shall not be less than 6 times/h [10]. The method of suffocation and extinguishing is usually adopted in the fire of the integrated pipe gallery [11], so this article mainly studies the inside of the pipe gallery in a closed state when a fire occurs in the integrated pipe gallery, and studies the spreading behavior of the cable fire of the pipe gallery.
Although FDS sets a higher grid accuracy in the fire simulation to be closer to the actual value, too high grid accuracy has higher requirements on the performance of the computer, usually the grid size is \(12\), and the calculation formula is as follows (1)–(2)

\[
D^* = \left( \frac{Q}{\rho_a c_p T_a \sqrt{g}} \right)^{\frac{1}{2}}
\]

\[
4 < \frac{D^*}{\delta_x} < 16
\]

In: \(D^*\) is the characteristic diameter of the fire source; \(Q\) is the heat release rate, KW; \(\rho_a\) is the air density, Kg/m\(^3\); \(c_p\) is the specific heat capacity, J/(Kg·℃); \(T_a\) is the ambient temperature, ℃; \(\delta_x\) is the grid size; \(g\) is the acceleration of gravity.

When the fire source power is 1MW, the grid size of the fire source location is set to 0.25m*0.25m*0.1m, and the grid for other areas is set to 0.5m*0.5m*0.5m.

4 Simulation results and analysis
This article mainly simulates the change of temperature and smoke in the pipe gallery by suffocating fire when a fire occurs in the urban underground comprehensive pipe gallery.

4.1 Smoke spread speed
The spread of smoke from urban integrated pipe gallery cable fire using suffocation extinguishing method is shown in Figure 2. It can be found that when a cable fire occurs in the middle of the pipe gallery, it takes about 150s for the fire smoke to spread to both ends of the pipe gallery. At this time, \(O_2\) in the pipe gallery Fires with higher concentrations are in the developing stage, and the spreading speed of fire smoke is 0.7m/s, which is less than the walking speed of adults. However, as the combustion continues, the \(O_2\) in the pipe gallery is consumed in a large amount, and the pipe gallery maintenance personnel need to evacuate to the escape ports at both ends as soon as possible.

Figure 2. Top view of smoke diffusion

As shown in Figure 3, the temperature change diagram of the cable cabin, it can be found that the \(O_2\) concentration in the integrated pipe gallery can still maintain the combustion and the flame is not completely extinguished during the first 226s. At this time, the temperature in the center of the pipe gallery continues to spread to both ends of the pipe gallery. After 226s, the oxygen concentration in the pipe gallery is not enough to support the disappearance of the burning flame and the burning ceases. After nearly 700s, the temperature of the flue gas in the pipe gallery gradually decreases, indicating that it is good to suffocate and extinguish the fire in the pipe gallery. Effective method to control the fire in the pipe gallery.
Figure 3. Temperature change diagram of the cable compartment.

As shown in Figure 4, the smoke temperature distribution diagram at the height of 1.7m of the human eye feature is mainly due to the high temperature smoke generated during the combustion process of the cable fire diffuses upwards and continuously entrains the lower surrounding cold air, thus forming the middle A parabolic shape with a higher temperature and a lower temperature on both sides. The distribution law of the flue gas also indirectly proves the fluidity of the flue gas. It can be seen from the figure that as the open flame is extinguished, the flue gas temperature in the pipe gallery drops rapidly, and the flue gas temperature basically tends to be stable when it drops to 300s, and meanwhile the temperature around 40°C basically maintains, which indicate that if the pipe gallery is overhauled at this time, the possibility of re-ignition is very small.

Figure 4. Temperature change graph at a characteristic height of 1.7m.

As shown in Figure 5, in the change curve of the O2 concentration, CO2 concentration, and CO concentration at the characteristic height of 1.7m in the center of the integrated pipe gallery, it can be found that the O2 concentration drops rapidly under the conditions of suffocation and extinguishing, and the concentration drops to 16% within 195s below, and the concentration quickly drops to zero within 520s. In the first 250s, the oxygen in the pipe gallery is sufficient, and the cable fire combustion is sufficient. The CO2 concentration increases rapidly. The CO concentration increases slowly. However, in the 250s to 515s, the O2 concentration in the pipe gallery decreases and the combustion is insufficient. At this stage, the CO concentration rises significantly. The obvious fluctuation of CO2 concentration indicates that the combustion is unstable at this time. The O2 concentration rapidly dropped below 16% within 195s, indicating that when a cable fire occurred, the construction workers in the pipe gallery needed to quickly escape from the escape port within 195s.
As shown in Figure 6, the height of the flue gas layer at the distance from the fire source to the pipe gallery cable fire decreases rapidly at the initial stage of development, and then the smoke diffuses along the ceiling to both ends, and the cable fire burns as the O$_2$ concentration in the pipe gallery decreases end. At this time, the fire smoke generated by the early fire combustion is less. After the subsequent simulation time, the fire smoke spreads evenly at the ceiling and finally evenly distributes at the ceiling of the pipe gallery.

As shown in Figure 7, it is a graph of the density change of the smoke layer at the height of 1.7m in the middle of the comprehensive pipe corridor. It can be found that the density of the smoke layer changes significantly in the first 517s, while the smoke concentration gradually tends to stability. The main reason for this phenomenon is that there is sufficient oxygen in the pipe gallery during the first 262s. At this time, there is a steady increase in the fire smoke concentration at the fire source. The smoke concentration of the fire still remains in the middle 262~517s. The large change is mainly due to the fact that although the amount of smoke generated at the fire source is reduced, the smoke concentration in the pipe gallery has not yet reached equilibrium at this time, and there is still more smoke in the middle part, so it is still necessary to continuously move to both ends. Diffusion is carried out, and the flue gas concentration basically reaches an equilibrium state after 517s.
5 Conclusion

In this paper, Pyrosim software is adopted to simulate the cable fire of the cable cabin of the integrated pipe gallery, and studies the development trend of fire if the method of suffocation is adopted. The main conclusions can be summarized as follows: (1) When the fire source power is 1MW, the open flame is completely extinguished in 262s, and O\textsubscript{2} is completely consumed in 530s. (2) The method of suffocating and extinguishing the fire in the integrated pipe gallery is adopted. At 300s after the fire, the temperature in the pipe gallery basically tends to be stable, basically maintaining at about 40°C. (3) The O\textsubscript{2} concentration quickly drops below 16% within 195s, and the O\textsubscript{2} concentration almost drops to zero within 515s. (4) The amount of fire smoke from the cable fire in the pipe gallery is less under the condition of suffocating and extinguishing the fire. At the end of the fire, the smoke concentration in the fire is only maintained at 0.015Kg/m\textsuperscript{3}. In terms of the future work, the suffocation fire extinguishing method should be carried out to control the cable fire of the pipe gallery.

References

[1] Kai Liang. Study on the Cables Fire Spread Behavior and Smoke Flow Characteristics of Urban Underground Utility Tunnel [D]. China University of Mining and Technology, 2020.
[2] Huang Ping, Deng Xi, Yu Longxing Numerical Simulation of the Performance of Fire Extinguishing by Water Mist in Utility Tunnel Cable Fire [J]. Safety and Environmental Engineering, 2021, 28(05):80-87.
[3] Yang Lizhong, Ye Kai. A review of research on fire safety codes and fire science in urban utility tunnels[J]. China Safety Science Journal, 2021, 31(08):132-140.
[4] Jia Boyan, Zhang Peng, Zhang Yuan-yuan, Xu Yaping, Wei Liqiang. Influence of fire separation and smoke extraction measures on the spread of smoke in utility tunnel cable fire [J]. Fire Science and Technology, 2021, 40(01):47-50.
[5] Liu Xin, Zhu Guoqing, Xu Gang. Study on fire behaviour of cable cabins in utility tunnel under low oxygen concentration [J]. Fire Science and Technology, 2021, 40(07):987-990.
[6] Liang, K.; Hao, X.; An, W.; Tang, Y.; Cong, Y., Study on cable fire spread and smoke temperature distribution in T-shaped utility tunnel. Case Studies in Thermal Engineering 2019, 14, 100433.
[7] Wang, P.; Zhu, G.; Pan, R.; Chu, T.; Wang, Z.; Liu, H., Effects of curved sidewall on maximum temperature and longitudinal temperature distribution induced by linear fire source in utility tunnel. Case Studies in Thermal Engineering 2020, 17, 100555.
[8] Wang, X.; Tan, Y.; Zhang, T.; Zhang, J.; Yu, K., Diffusion process simulation and ventilation strategy for small-hole natural gas leakage in utility tunnels. Tunn. Undergr. Space Technol. 2020, 97, 103276.

[9] Du Changbao. Analysis of Temperature Field Distribution and Smoke Flow Characteristics of Cable Fire in Underground Pipe Gallery[D]. China University of Mining and Technology, 2017.

[10] Mi Hongfu, Liu Yaling, Yang Wenjing, Wang Wenhe, Zhu Zhengxiang, Huang Wei, Tang Liang, Jiao Yifei. Research on optimization control mode of smoke for cable fire in utility tunnel based on FDS [J]. Journal of Safety Science and Technology, 2020, 16(07):100-105.

[11] Sun Weijun. Fire danger of urban underground pipe control technology research [D]. Xi’an University of Architecture and Technology, 2017.

[12] Li Jian, Shi Congling, Li Yunsong, Zhang Xiaolei. Research on influence mechanism of crossing angle between tunnel and cross passage on fire smoke spread [J]. Journal of Safety Science and Technology, 2020, 16(07):36-42.