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Research and Analysis of Subway Platform Fire Risk and Control Strategy

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Abstract: *In order to study the threat of subway platform fires to subway safety and how to reduce the impact of fires on subway safety through mechanical smoke exhaustion systems, this article used FDS software for numerical simulation to explore the influence of the opening of the platform smoke-screen doors on the smoke flow pattern during fires. The article set three typical fire simulation scenarios, and through the analysis of the simulation data, it was found that when the platform smoke-screen doors were in the open state, the time for smoke to spread to the concourse could be extended, and the height of the smoke layer could be effectively reduced. However, it is best to open the smoke-screen doors on both sides of the subway platform at the same time to achieve rapid smoke exhaust and provide valuable time for safe evacuation of personnel.*

Keywords: *Fire; Subway platform; Smoke-screen door; Exhaust smoke; FDS*

1. Introduction

As China's economy continues to improve and urban areas expand, the development of the subway industry can improve urban traffic flow, alleviate road traffic pressure, and facilitate intercity communication and transportation. However, if a fire occurs during subway operation, especially on the platform, it can cause significant damage [1]. In recent years, research on subway fires in China has gradually increased. Zhou Yu et al [2] conducted fire simulation experiments and questionnaire surveys, and found that passenger age, fire type, and smoke concentration all affected evacuation behavior. Yang Xin et al [3] analyzed the sensitivity of evacuation speed to duration and channel width through fire simulation experiments. Ramaekers M. et al [4] reviewed micro- and macro-scale simulations of subway platform pedestrian flow and emergency evacuation, and analyzed their application and limitations. Liu, J. et al [5] analyzed the evacuation efficiency and safety of passengers on a subway platform under different strategies using CFD and discrete event simulation. The above studies have focused on different aspects of subway platform fires and are of great significance for ensuring subway safety.This article focuses on studying the smoke flow characteristics of platform fires and providing corresponding control strategies based on fire risk, providing reference for the construction and fire safety management of subway stations.

2. Smoke Flow Characteristics of Subway Platform Fires

2.1 Study on the Development Stages of Smoke Flow on Subway Platforms

The aspect ratio of subway platforms is large with a height generally below 4m. It is a typical narrow and long space structure. The most widely used classification of smoke flow development in such confined spaces is into four stages[6]:

Stage I: The smoke plume rises and impacts the ceiling, which is similar to an ordinary room. The smoke plume flows upward due to buoyancy and eventually reaches the ceiling and collides with it. During the upward flow, the smoke plume continuously entrains the surrounding air, leading to an increase in mass.

Stage II: After the smoke plume impacts the ceiling, it spreads freely along the ceiling. This stage mainly depends on the length and width of the space, and it will be blocked by the side walls after spreading freely for a certain period.

Stage III: The smoke plume transitions from radial spread to one-dimensional spread. Under the action of the side walls, it forms an anti-buoyancy jet similar to an ordinary room, moves downwards for a certain distance and then moves upwards under the action of buoyancy. During this process, the surrounding air is entrained, leading to an increase in mass.

Stage IV: The smoke plume moves in one-dimensional horizontal direction, forming a hot smoke layer along the long axis of the space. During the one-dimensional movement, cold air is still entrained into the smoke layer. When the one-dimensional smoke spreads to the end of the space, it is blocked by the side wall, forming an anti-buoyancy jet and finally forming a hot smoke layer at the top of the entire space.

2.2 Study on the Flow Characteristics of Smoke in Subway Station Platforms

Subway platforms generally use smoke-blocking hanging walls to divide smoke-proof zones, which can limit the flow of smoke horizontally. Each smoke-proof zone has a corresponding smoke exhaust port to exhaust the smoke in that zone. When the smoke exhaust capacity is insufficient or fails, the smoke will spread to adjacent smoke-proof zones.

In the vertical direction, the subway platform and hall are mainly connected at the escalator and staircase entrances. If there is no effective smoke control measures, when the smoke spreads to the connecting entrance, it will spread to the station hall layer. If the fire cannot be effectively controlled for a long time, the smoke will eventually fill the spaces of the fire layer and the upper layers.

After a fire occurs on the subway platform, if the smoke is not effectively controlled, the direction of smoke spread happens to be the direction of personnel evacuation. The openings of escalators and staircases are both the only way for personnel evacuation and the openings for smoke to spread to the station hall layer. The ground exits are both the openings for smoke to spread to the ground and for personnel evacuation to the ground, as well as the openings for fresh air to flow into the platform. Therefore, if smoke control is not handled properly, smoke will block the passage of personnel evacuation and firefighters' rescue, which will seriously threaten the safety of personnel evacuation and fire fighting.

3. Research on Smoke Control Methods for Subway Platforms

3.1 Introduction of research methods

The FDS software is an important tool for studying the development of fire smoke. The software was developed by the Fire Research Laboratory of the National Institute of Standards and Technology in the United States and has been validated through full-scale fire experiments [7]. Currently, the software has been widely used in domestic and international fire simulation research. FDS uses a computational method based on field simulation to solve the spatial state parameter distribution and time variation using partial differential equations. This paper will use the software to model fire scenarios and study the flow patterns of smoke in a subway platform fire.

3.2 Analysis and research on platform exhaust

The underground subway station platform has a narrow space and limited smoke accumulation space. It only has one connection to the ground through the entrance and exit of the subway station. Therefore, natural smoke exhaust is not effective in removing fire smoke. Therefore, mechanical smoke exhaust is a common smoke exhaust method used in subway stations. To save energy, reduce the interference of tunnel vehicle operations on the station, and ensure the safety of passengers, most newly built stations have protective doors installed between the platforms and station tunnels. After a fire occurs on the platform, the protective doors are opened after confirming that the trains on both the up and down lines have passed through the station. With the assistance of the mechanical smoke exhaust system on the track roof, smoke is discharged. However, opening the protective doors will bring certain wind pressure to the platform, reducing the wind speed downwards at the staircase, which may cause the smoke to accelerate and spread to the station concourse. In this section, FDS software will be used to simulate and analyze the impact of the number of protective doors opened on the mechanical smoke exhaust effect, providing reference for designers to design the best smoke exhaust effect and reducing the risk of injury to personnel.

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3.3 Fire model building

To further study the smoke exhaust situation on the station platform, the simulation scenario set by the research institute is a fire on a station platform. The specific fire scenario is a luggage fire on the platform, assuming that two luggage boxes catch fire at the same time. Referring to the weight data of large luggage bags and leather cases in China, the average weight is about 6.4kg. Therefore, the maximum heat release rate of the simulation scenario is set to 730kW. The fire source is located between the openings of the two escalators on the platform, as shown in Figure 1.

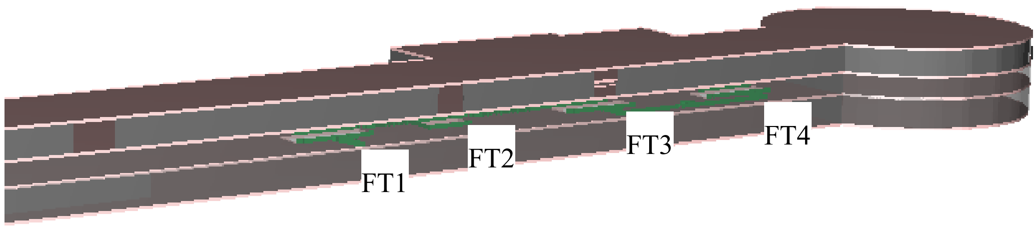

Figure 1: Schematic diagram of fire source location

In order to compare the effects of different protective door opening methods on smoke flow, three fire scenarios were set, as shown in Table 1, where the smoke exhaust volume is set according to the actual subway design as 120000 m3/h, with a total of 18 smoke exhaust ports and natural air supply at the concourse level.

Table 1: Fire simulation scene and parameter setting table in the middle of the station

Scenario	Fire form	Maximum ignition power /kW	Smoke-screen door switch form
Scenario 1	Station luggage fire	730	Close the platform smoke-screen doors
scenario 2	Station luggage fire	730	Open the platform one side smoke-screen door
scenario 3	Station luggage fire	730	Open the platform smoke-screen doors

4. Simulation result analysis

The FDS simulation software was used to simulate and calculate the above three fire simulation scenarios. In order to compare and analyze the differences between each group of scenarios, this article studies the smoke propagation process, smoke layer height, ceiling temperature, vertical temperature distribution.

4.1 Influence of flue gas spreading process

The smoke propagation process video can be obtained through the FDS simulation software, and Figure 2 shows a group of pictures with typical smoke propagation characteristics that were selected. According to the smoke propagation process in fire scenario 1 shown in Figure 2, after the luggage in the middle of the platform catches fire, the smoke rises in an axisymmetric plume form and reaches the ceiling at T=6 seconds. Once it reaches the ceiling, the smoke begins to spread radially. At T=34 seconds, the smoke plume changes from two-dimensional motion to one-dimensional motion due to the effect of the sidewalls, and at T=86 seconds, some of the smoke spreads from the openings of the escalators 2 and 3 to the concourse level. At T=224 seconds, the smoke layer basically forms a stable state. Throughout the entire smoke propagation process of fire scenario 1, it conforms to the typical development law of smoke in narrow space fires.

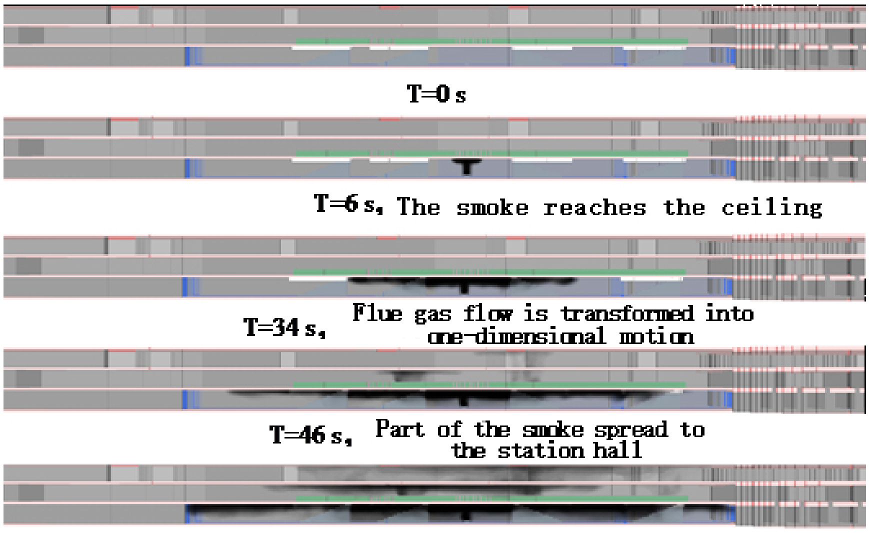

Figure 2: Smoke spreading process in fire scenario 1

The typical smoke propagation process of fire scenario 2 is shown in Figure 3. Following the smoke flow laws of subway platforms, the smoke layer basically forms a stable state at 98 seconds, and the smoke propagation process conforms to the typical development law of smoke in narrow space fires.

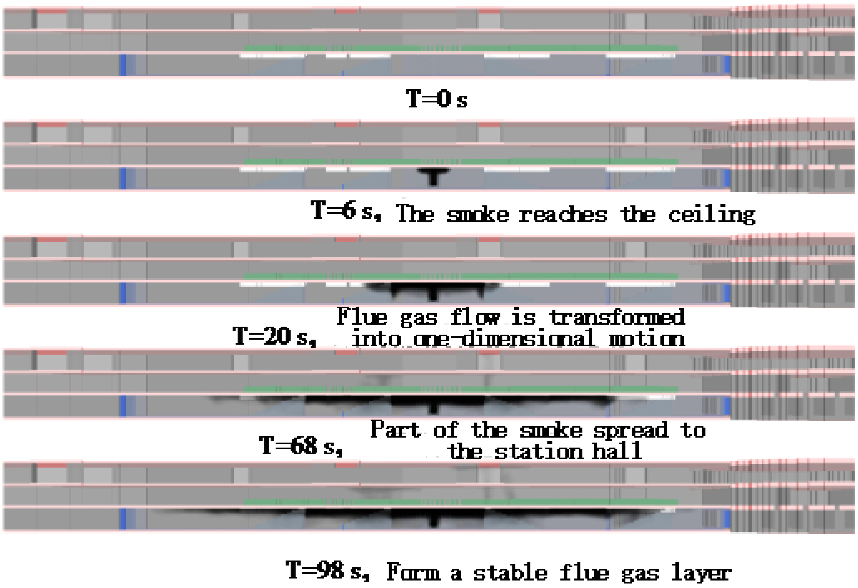

Figure 3: Smoke spreading process in fire scenario 2

The typical smoke propagation process of fire scenario 3 is shown in Figure 4, and the smoke layer basically forms a stable state at 74 seconds. The smoke propagation process conforms to the typical development law of smoke in narrow space fires. A comparison of the smoke propagation situations in the three fire scenarios reveals that opening more smoke-screen doors can prolong the time required for smoke to spread to the station hall level, which can be more helpful for safe evacuation of people.

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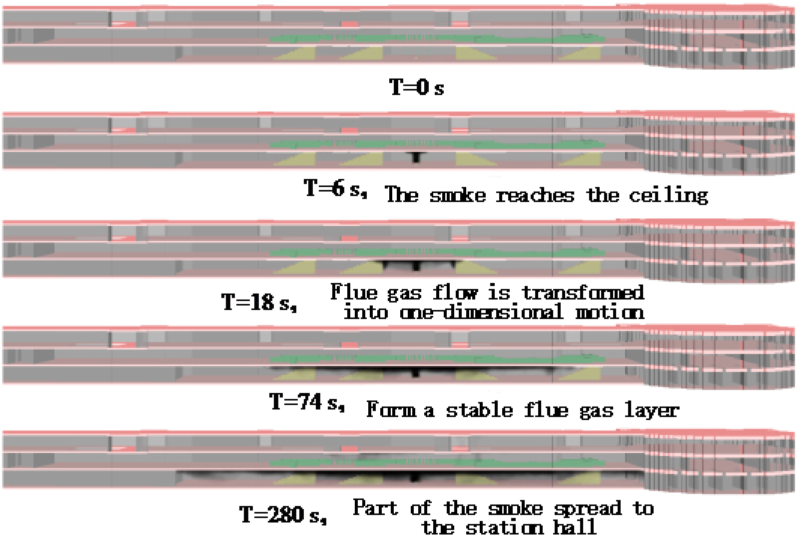

Figure 4: Smoke spreading process in fire scenario 3

4.2 Analysis of influence of flue gas layer height

The smoke layer height data obtained from FDS simulation software is shown in Figure 5, indicating that the smoke layer drops rapidly in the early stages of the fire and is not affected by whether the smoke-screen doors are opened or not. As the combustion continues to develop, with all smoke-screen doors closed on the platform, the smoke layer height drops to about 2.9 meters above the ground; with one side smoke-screen door open, the smoke layer height drops to about 3.1 meters above the ground; with all smoke-screen doors open, the smoke layer height drops to about 3.3 meters above the ground. The simulation results show that opening the smoke-screen doors can effectively reduce the thickness of the smoke layer. In addition, the simulation results also indicate that the more smoke-screen doors are opened, the greater the fluctuation in smoke layer height. Opening the smoke-screen doors can interfere with the stratification of the smoke layer and play a certain role in reducing the thickness of the smoke layer.

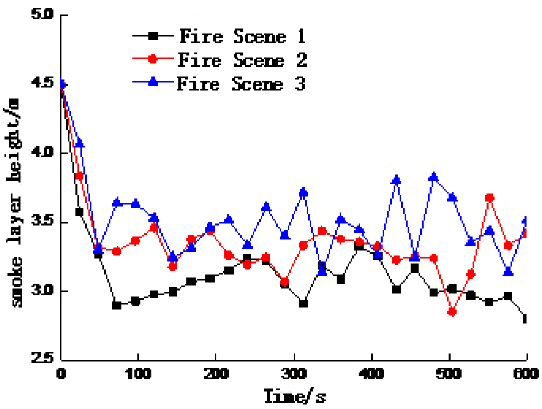

Figure 5: Height curve of flue gas layer

4.3 Effect analysis of flue gas temperature

4.3.1 Ceiling temperature

The variation of ceiling temperature distribution for three different fire scenarios is shown in Figure 6. In scenario 1 and scenario 3, the ceiling temperature on the platform exhibits clear symmetry, with the temperature peak on the left side of the fire source. In scenario 1, the highest temperature of the ceiling smoke is 170°C, while in scenario 3, the highest temperature is 98°C. In scenario 2, the ceiling

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temperature on the right side of the fire source is slightly higher than that on the left side, and the highest smoke temperature is on the right side of the fire source, at 115℃. In addition, in scenario 2, the ceiling smoke temperature curve on the left side of the fire source is above that in scenario 1 on the left side, indicating that when one side of the smoke-screen door is opened, the ceiling smoke temperature will accumulate to one side. When more smoke-screen doors are opened in scenario 3, the area where the temperature on the ceiling is higher than 60℃ is relatively small, indicating that opening more smoke-screen doors is beneficial to reducing the temperature. However, when only one side of the smoke-screen door is opened, the smoke above the fire source will tilt due to the unbalanced flow of smoke, causing the smoke to flow to one side of the subway platform. At this time, the ceiling smoke temperature on the right side is even higher than that without opening any doors. In summary, to effectively reduce the smoke temperature on the ceiling and prevent the smoke from tilting in the event of a fire, both sides of the smoke-screen door should be opened simultaneously.

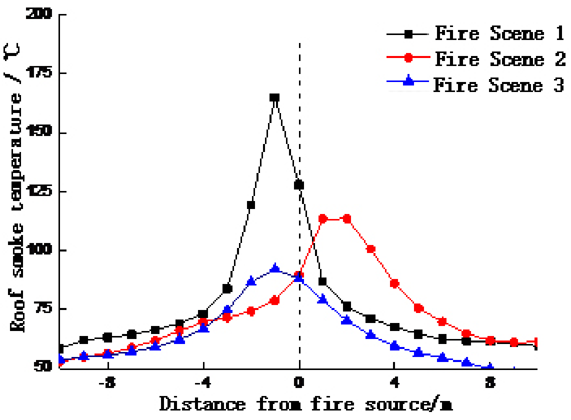

Figure 6: Ceiling flue gas temperature curve

4.3.2 Influence analysis of vertical temperature distribution

The variation of vertical temperature distribution for three different fire scenarios is shown in Figure 7. At a height of 0.5m from the ground, the fire plume temperature in scenario 2 is the highest, indicating that when one side of the smoke-screen door is opened, the combustion of the fire source is more complete, leading to an increase in the fire plume temperature. On the other hand, when both sides of the smoke-screen door are opened, the smoke temperature is significantly lower than that in the scenarios where no doors are opened and only one side is opened, which is more conducive to the evacuation of personnel.

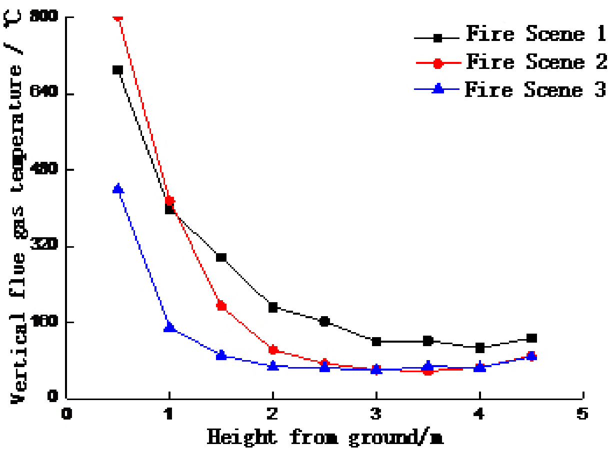

Figure 7: Temperature distribution of flue gas above the fire source

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5. Conclusion

This article uses FDS simulation software to study the impact of different opening modes of smoke-screen doors on the flow pattern of fire smoke. By setting three typical fire simulation scenarios, the smoke control strategy that is conducive to personnel evacuation is obtained. When a platform fire occurs, it is necessary to open both sides of the smoke-screen door, which can reduce the temperature of the ceiling and vertical smoke, and has a relatively good smoke exhaust effect, providing conditions for safe evacuation of personnel.

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