

Fire simulation and smoke spread analysis of subway stations at different fire locations

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Abstract. In order to explore the law of smoke spread in the fire environment of an island-style subway station, this article takes an island-style subway as the research object. Based on the fire dynamics, pyrosim is used to establish a subway fire model to observe the smoke concentration and temperature changes under different fire locations. The study found that when the fire source is at the end of the platform layer, the flue gas concentration of the farthest evacuation channel and safety exit reaches 80% at 85s and 130s, respectively, and the flue gas temperature at the nearest exit and the farthest exit are at 32°C and 28°C respectively. When the fire source is in the middle of the platform layer, the smoke concentration of the evacuation channel and the safety exit reaches 80% at 70s and 105s respectively, and the temperature of the smoke at the exit exceeds 40°C.

1 Introduction

With the development of the world's urbanization process, the population density in highly developed cities has gradually increased, and the construction requirements of urban public transportation have also increased. Among the many means of transportation, the subway has the

advantages of small footprint, large passenger capacity, and stable operation. It is the best choice for most people to travel. However, the subway also has the characteristics of large flow of people, prone to congestion, and long evacuation time. Once a fire occurs, it is very easy to cause serious casualties. Table 1 summarizes some subway fire incidents in countries around the world [1].

Table 1. Subway accident sorting.

Time	Accident
February 2003	An arson occurred at a subway station in Daegu, South Korea, causing 198 deaths and 146 injuries.
December 2003	A fire broke out in a shopping mall adjacent to a subway station in Shanghai, China, and smoke spread to the subway station.
June 2013	A power line failure at a subway station in Moscow, Russia caused 52 people to be injured and about 4,500 people were evacuated urgently.
January 2015	A fire broke out in a subway in Washington, U.S., causing 1 death and 2 injuries
October 2016	An unknown substance burned in the vent of a subway station in Tokyo, Japan, and the subway was suspended.
June 2018	A subway station in London, the United Kingdom exploded due to overheating of electronic equipment, and a large amount of smoke spread in the subway station.
October 2019	Arson occurred at multiple subway stations in Hong Kong, China, and the subway was paralyzed.

Therefore, the subway fire is of great research value and practical significance. Park et al. established a numerical model to study the diffusion rate of smoke at different locations in a subway fire, and analyzed and compared the distribution of smoke, temperature, and

visibility under different exhaust power^[2]. Pan et al. conducted experiments in underground stations to study the inhibitory effect of water mist on smoke diffusion^[3]. Pyrosim software is that the simulation model established by the software is closer to the actual fire, and it is widely

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used in the fire scenes of various buildings^[4, 5, 6].

Based on fire dynamics, this paper takes a subway station as the research object and establishes a simulation model through Pyrosim, and obtains the smoke concentration changes and temperature changes of the stairs and exits near different fire sources in subway fires.

2 PRELIMINARIES

Fire Dynamic Simulation (FDS) is a computational fluid dynamics (CFD) model of fire-driven fluid flow, and it is also the most widely used fire calculation simulator^[7]. Fire dynamics believes that fire is a physical and chemical process, and its combustion process obeys the following conservation laws:

(1) Continuity equation:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot \rho \vec{\mu} = 0 \quad (1)$$

$$\nabla \cdot \vec{\mu} = \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} \quad (2)$$

Where, ρ is the density; t is the time; $\vec{\mu}$ is the speed; and, u , v and w are the components of the speed in the three coordinate axis directions.

(2) Conservation of momentum:

$$\rho \left(\frac{\partial u}{\partial t} + (u \cdot \nabla)u \right) + \nabla p = \rho g + f + \nabla \cdot \tau \quad (3)$$

Where, g is the acceleration due to gravity; f is the externally applied force vector; τ is the viscous force tensor; p is the pressure.

(3) Energy equation:

$$\frac{\partial}{\partial t} (\rho h) + \nabla \cdot (\rho h u) = \frac{\partial p}{\partial t} + u \cdot \nabla p - \nabla \cdot q_r + \nabla \cdot (k \nabla T) + \sum_i \nabla \cdot (h_i \rho D_i \nabla Y_i) \quad (4)$$

Where, h is the enthalpy (J/kg); q_r is the thermal radiation energy; T is the temperature; k is the thermal conductivity.

3 Simulation modeling

This paper takes an island-style subway station as the research object, and establishes a physical model in the software Pyrosim according to its basic situation and spatial structure. The top view is shown in 1. The station hall floor B0 and the station floor B1 are both 115m long, 24m wide, 4.5 m high, and the total area is about 5520.0 m². There are two stair evacuation passages between the station floor and the hall floor, and there are two on each side of the wall of the station hall floor. There are 48 screen doors evenly distributed on both sides of the platform layer.

Pyrosim can observe the smoke concentration, smoke height and temperature changes in the subway station when a fire occurs, and add 24 smoke detectors and 24 temperature detectors, 3 carbon monoxide concentration measuring devices, and 4 slice devices. Display 2D outline. In order to observe the influence of fire development at different fire source locations, and to study its smoke content and temperature changes, this

paper sets up 4 fire scenarios:

In the Case1, is the fire source is at position 1, on the left side of the platform

Case2: The fire source is at position 2, located on the platform level.



Figure 1. Main view of subway station

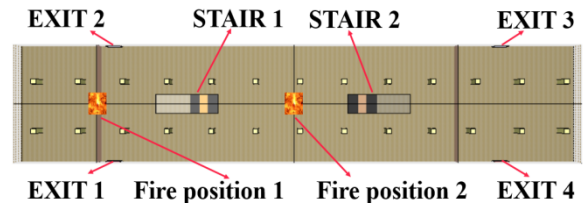


Figure 2. Top view of subway station

4 Results and analysis

According to the above model, the fire simulation is performed in Pyrosim, and the result at 600s is shown in Figure 3. Although most of the passengers carried are combustibles, the construction materials of subway stations are basically fireproof materials, so this article only simulates the combustion and smoke near the fire source. It can be found that the higher smoke concentration in Case1 is at the end of the subway near the fire source, while the smoke concentration and flame temperature in Case2 are basically symmetrical.

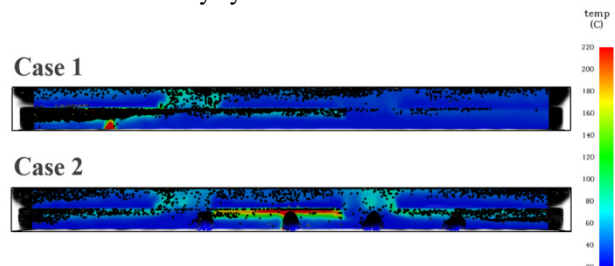


Figure 3. Temperature distribution of smoke and fire source in subway station at 600s

In Case 1, exit 1 and exit 2 are the closest to the fire source, and the flue gas concentration changes near stairs 1, stairs 2 and exit 4 are shown in Figure 4. It can be seen that the smoke concentration of staircase 1 rapidly exceeded 80% in the 40s after the fire, while staircase 2 exceeded 80% at 85s, and the exit 4, which is the farthest from the fire source, gradually exceeded 80% after 130s. In Case 2, the distances from the two stairs to the fire source are equal, and the distances from the 4 exits to the fire source are also equal. The flue gas concentration changes near staircase 1, staircase 2 and exit 4 are shown in Fig. 5. It can be seen that at about 70s, the smoke concentration near staircase 1 exceeds 80%. After 105s, the flue gas concentration near the outlet 4 gradually rises to about 75%.

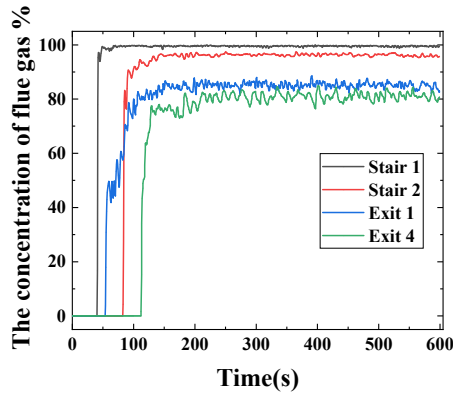


Figure 4. Smoke height at Case 1

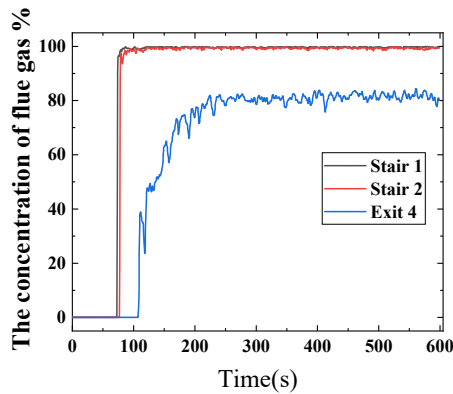


Figure 5. Smoke height at Case 2

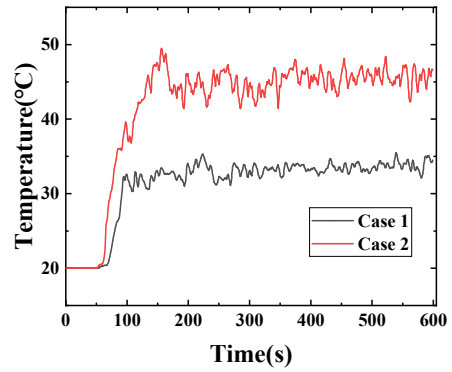


Figure 7. Temperature near exit 2

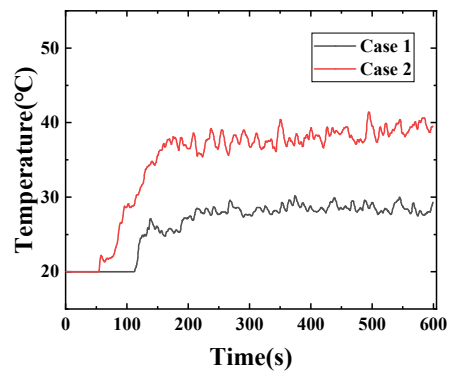


Figure 8. Temperature near exit 3

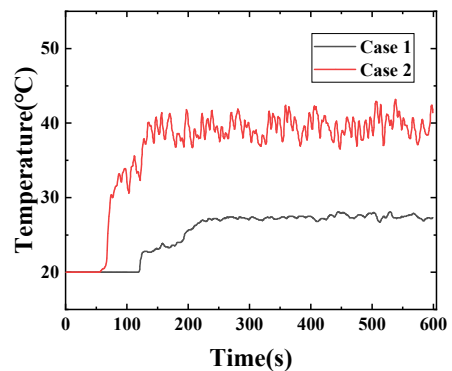


Figure 9. Temperature near exit 4

The temperature changes near the four exits are shown in Figures 6 to 9. It can be seen that because there are fewer combustibles in the subway station, the fire cannot spread to the hall floor, but the flue gas temperature gradually rises. When the fire source is located at the end of the platform floor, the temperature of the flue gas near the nearest exit is about 30°C. The flue gas temperature at outlet 3 and outlet 4 gradually increased after 110s, and finally stabilized at 25°C. When the fire source is in the middle of the two stairs, the temperature of the 4 outlets all rise gradually after 40s, and fluctuates around 40°C.

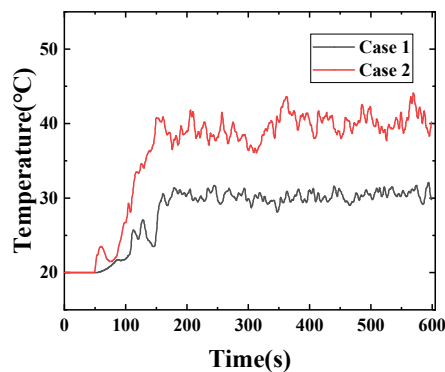


Figure 6. Temperature near exit 1

5 Conclusion

Today, when the subway construction tells the development, the subway fire safety issue has new challenges. In order to study the fire safety of subway buildings, this paper uses Pyrosim software to establish a fire simulation model for subway stations. From the modeling results, it is observed that when the subway station is composed of fireproof materials, and with a single fire source which is at the end of the subway platform, the smoke concentration at the nearest stairs, the furthest stairs, the nearest exit and the furthest exit reaches 80% after 40 s, 85 s, 95 s and 130 s, and the smoke temperature at the exits is below than 32°C. When the fire source is in the middle of the platform floor, the smoke concentration near the stairs and the exit reaches 80% at

70s and 105s, respectively, and the exit temperature exceeds 39°C. The farther the fire source is from the exit and the evacuation channel, the longer it will take for the smoke concentration and temperature to reach a threat to human health, and the more time left for people to evacuate.

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