Study on Smoke Prevention Strategy of No Evacuation Fire Door in Metro Tunnel

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Abstract. The evacuation channel of the Metro tunnel serves as a corridor for the evacuation of two Metro tunnels. The trapped people need to open two fire doors at both ends of the evacuation channel. However, the fire door is a one-way fire door, and the narrow one can only be passed by one person, which is easy to cause people to block and reduce the evacuation efficiency. Therefore, it is proposed that no fire doors should be set in the evacuation channel, the accident tunnel uses the push-pull air supply mode, and the non-accident tunnel uses the double-side air supply mode strategy for smoke control. Through experimental research, it is concluded that: This mode can effectively control the flue gas and prevent the flue gas from entering the non-accident tunnel. At the same time, the fresh air of the control system has good cooling effect.

1. Introduction
Unlike general ground buildings, Metro is a closed underground space. Once a fire occurs, it will have the characteristics of typical confined space. It has the characteristics of strong sudden, rapid spread of fire, high temperature in cavern, complex situation and difficulty in fire extinguishing [1]. If the train is difficult to get out of the tunnel after fire, and the people are not evacuated quickly, the rapid development of fire and the smoke accumulated in the tunnel may cause serious casualties [2]. In Metro tunnels, two tunnels are usually evacuation channel each other. The trapped people need to pass the fire door which can only be opened one way through the evacuation channel before evacuating through the accident tunnel to the non-accident tunnel and reaching the safe area [3]. However, the fire door is often narrow and can only be passed by one person, so it is very easy to cause people blocking and reduce evacuation efficiency. Therefore, choosing a scientific and effective smoke exhaust ventilation mode to form the air flow to non-accident tunnel at the evacuation channel can produce smoke blocking effect, which can replace the fire door and improve the evacuation efficiency when people evacuate.

2. Control scheme and principle
Since the vents of the actual Metro tunnel ventilation system are generally arranged on both sides of the platform. For general Metro tunnels, when the train is in fire and stops in the tunnel, the accident tunnel will choose to open the accident tunnel push-pull air supply control mode in a reasonable direction of air supply, and the non-accident tunnel will not take any action in principle, which can effectively control the flue gas flow [4]. However, when the fire door is not set in the evacuation
channel, the effective control of smoke will not be realized due to the lack of separation in the evacuation channel. If the fan on both sides of the non-accident tunnel opens the air supply mode by changing the direction of the fan or adjusting the air valve. The evacuation channel can form a gas flow from the non-accident tunnel to the accident tunnel, and the purpose of preventing the accident tunnel smoke from entering the non-accident tunnel. The air distribution of the control scheme is shown in Figure 1 for a metro tunnel with a length of more than 1200 m and two evacuation channels.

3. Experimental method
According to the fire characteristics of trains in Metro tunnels, a fire smoke control scheme for interval tunnels without fire doors is designed. Ventilation system and measurement system are deployed in scaled model tunnels for experiments. The feasibility of the smoke control scheme is analyzed through the smoke control effect of the evacuation channel and the temperature change in the tunnel.

3.1. Experimental platform
The experimental platform is a 1:3 tunnel model based on a typical single-tunnel and double-track Metro tunnel. The experimental platform is 75 m long, 3.5 m wide and 2 m high. There are two non-fire door evacuation channels at 22.5 m and 52.5 m respectively. The height and width of the communication channel are 0.7 m and 0.3 m respectively, and the distance between the two channels is 0.5 m. The specific size of the experimental platform is shown in Figure 2.

3.2. Fire source design
According to the "Standard for Fire Protection in Metro Design" GB1298-2018, currently the design fire scale in China is usually 7.5 MW~10.5 MW [5]. Rubber tyres have been widely studied because of their typical characteristics of solid fire and rapid fire growth rate. They are commonly used in tunnel fire smoke control tests because of their relatively durable combustion and easy observation of experimental phenomena [6]. Calibration test of heat release rate shows that rubber tyres weighing about 12 kg can reach the range of heat release rate. Therefore, in this fire smoke control test, rubber tyres of about 12 kg were selected as burners.

3.3. Ventilation system design
The smoke control system of the model Metro tunnel includes the push-pull air supply system of the accident tunnel and the air supply system of both sides of the non-accident tunnel. The air supply end of the push-pull air supply system in the accident tunnel is an axial fan with air volume of 121 770 m$^3$/h, and the exhaust end is two jet fans with air volume of 14 000 m$^3$/h. The wind speed of 1.75 m/s is formed in the tunnel through debugging. The air supply system on both sides of non-accident tunnel
is composed of two axial fans with 28 440 m³/h typhoon volume, and the wind speed is 1.5 m/s when
the fan starts separately through debugging.

![Ventilation system equipment layout](image)

**Figure 3. Ventilation system equipment layout**

### 3.4. Measurement system

The measurement system mainly includes temperature measurement system and heat release rate
measurement system. The temperature measurement system uses armored K-type nickel-chromium-
nickel-silicon thermocouple. The measuring point is located in the middle of the tunnel and 10 cm
away from the top. There is a measuring point every 7.5 m in both accident and non-accident tunnels.
And there is a temperature series consisting of four thermocouples on the side of the non-accident
tunnel of the evacuation channel. The heat release rate measurement system is based on the principle
of weightlessness method. The weighing instrument with accuracy of 0.01 kg is used to record the
weight of burning materials in real time, and the weighing instrument needs to be arranged under the
burning materials. The layout of the measurement system is shown in Figure 4.

![Layout of measuring points](image)

**Figure 4. Layout of measuring points**

### 4. Experimental results and analysis

#### 4.1. Combustion of Fire Source

The mass loss rate of tire can be calculated according to the change of tire mass measured by
experiment. Then the heat release rate curve of tire combustion can be obtained by using the heat
release rate formula of weightlessness method, as shown in Figure 5.

![Variation curve of heat release rate of fire source](image)

**Figure 5. Variation curve of heat release rate of fire source**

From the heat release rate curve of the fire source, it can be seen that the heat release rate of the fire
source increases rapidly after ignition, reaches 519 kW at 102 seconds and tends to be stable gradually.
Its fire growth coefficient is 0.050 kW/s². At 162 seconds, the heat release rate of the fire source
reaches a peak of 565 kW. At 369 seconds, the heat release rate begins to decrease gradually, and the
combustion of the fire source gradually ends after 1200 seconds.
4.2. Flue Gas Phenomenon in Evacuation Channel
From the smoke phenomena of the evacuation channel in Figure 6, it can be seen that the smoke enters the non-accident tunnel through the 1# evacuation channel 50 seconds after the ignition of the fire source. At 80 seconds, when the air supply system of accident tunnel and non-accident tunnel is opened, the smoke of 1# evacuation channel suddenly increases greatly, and 2# evacuation channel also begins to have smoke entering. After 90 seconds, the smoke will no longer enter the non-accident tunnel through the 2# evacuation channel. And after 110 seconds, the smoke will no longer enter the non-accident tunnel through the 1# evacuation channel.

It can be concluded that the flue gas will enter the non-accident tunnel through the evacuation channel before the ventilation system is turned on. After the accident tunnel and the non-accident tunnel ventilation system are opened, the flue gas can quickly and effectively prevent the entry into the non-accident tunnel.

4.3. Temperature Variation at Evacuation Channel of Non-accident Tunnel Side
From the temperature variation curve of 1# evacuation channel on the side of non-accident tunnel in Figure 8, it can be seen that the temperature of each point in 1# evacuation channel increases gradually after ignition of fire source, even after opening the flue gas control system, the temperature is still rising. The maximum temperature of flue gas at 1# evacuation channel of non-accident tunnel is 40.6 °C, and the temperature decreases gradually from top to bottom.

It can be concluded that the flue gas will enter the non-accident tunnel through the evacuation channel before the ventilation system is turned on. After the accident tunnel and the non-accident tunnel ventilation system are opened, the flue gas can quickly and effectively prevent the entry into the non-accident tunnel.
flue gas control system. After turn the flue gas control system, the temperature of each measuring point rises briefly, the maximum temperature is 37 °C, and then decreases rapidly.

![Temperature curve of accident tunnel](image1)

Figure 8. Temperature curve of accident tunnel

It can be concluded that when the fire source is located near 1# evacuation channel, the smoke control system can not prevent the temperature of the non-accident tunnel from rising continuously, but the temperature is within a safe range. At the initial time of opening ventilation system, 2# evacuation channel will promote smoke entering and evacuating passage to non-accident tunnel, which will increase the temperature of non-accident tunnel, but this phenomenon is relatively short.

4.4. Temperature Distribution of Accident Tunnel

From the longitudinal temperature variation curve of the accident tunnel in Figure 9, the temperature of the tunnel rises rapidly after the ignition of the fire source. The maximum temperature of the upstream measuring points of the fire source is 113 °C. After the flue gas control system is opened, the temperature of the upstream measuring points of the fire source decreases rapidly, while the maximum temperature of the downstream measuring points of the fire source is 112 °C.

![Temperature curve of accident tunnel](image2)

Figure 9. Temperature curve of accident tunnel

It can be concluded that the flue gas can be quickly and effectively controlled after the accident tunnel ventilation system is turned on, and the upstream entry of the fire source into the fresh air can also make the temperature drop rapidly.
4.5. Temperature Distribution in Non-accident Tunnels

From the longitudinal temperature variation curve of the non-accident tunnel in Figure 10, it can be seen that the smoke enters the non-accident tunnel before opening the air supply on both sides of the non-accident tunnel, and the maximum temperature of the non-accident tunnel temperature measurement point is 37.8 °C. When the air supply system on both sides of the non-accident tunnel is opened, the temperature decreases rapidly.

Figure 10. Temperature curve of non-accident tunnel

It can be concluded that after opening the ventilation system of non-accident tunnel, smoke can be effectively prevented from entering non-accident tunnel through transverse evacuation passage, and fresh air can quickly reduce the temperature of tunnel.

5. Conclusion

When there is no fire door in transverse evacuation passage, push-pull air supply mode is adopted in accident tunnel and double-side air supply mode is adopted in non-accident tunnel. Through the experimental study of smoke control in model Metro tunnel, the following conclusions are drawn:

1) Push-pull air supply mode is adopted in accident tunnel and double-side air supply mode is adopted in non-accident tunnel, which can effectively control the flue gas of accident tunnel, and the flue gas will not enter non-accident tunnel through evacuation channel.

2) When the smoke control system is opened, in order to avoid the sudden increase of smoke entering the non-accident tunnel through the transverse evacuation channel, the smoke control system on both sides of the non-accident tunnel should be started first, and then the push-pull air supply system of the accident tunnel should be started.

3) Reasonable flue gas control system can not only effectively control the flue gas, but also have an obvious cooling effect on the fresh air entering, which can make the temperature of smokeless area rapidly reduce after the flue gas control.

After the completion of the smoke control experiment, considering the safety of evacuation of subway tunnel personnel, the wind speed of the evacuation passage was systematically tested. It is found that the push-pull air supply in accident tunnel and the air supply on both sides of non-accident tunnel are used as smoke control strategies. In subway tunnels with two evacuation channels, there is a certain difference in wind speed between the two evacuation channels, and the difference is also related to train location and fire source location.

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