IOP Conference Series: Materials Science and Engineering

PAPER • OPEN ACCESS

Experimental Study on Smoke Control Scheme for Quasi-rectangular Tunnel Fire

To cite this article: Jixin Tang *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **569** 042061

Experimental Study on Smoke Control Scheme for Quasi-rectangular Tunnel Fire

Jixin Tang[1], Jingxuan Wang[2*], Dongfang Wang[1], Wei Zhao[3], Shichang Lu[4], and Wanfu Liu[2]

[1] Ningbo Rail Transit Group Co. Ltd., Ningbo, Zhejiang, 315101, China

[2] Tianjin University of Commerce, Tianjin, 300134, China

[3] Tianjin China Railway Electrification Design and Research Institute Co. Ltd., Tianjin, 300250, China

[4] Tianjin Fire Research Institute of MEM, Tianjin, 300381, China

[*] 790814353@qq.com

Abstract. Taking a quasi-rectangular Tunnel in a city as a prototype, a 1:3 scale tunnel test platform is built. Through the analysis of the smoke spread phenomenon and the change of tunnel longitudinal smoke temperature, the smoke exhaust effect of the quasi-rectangular tunnel with longitudinal ventilation in the ignition tunnel and positive pressure ventilation in the non-ignition tunnel is explored. The test results show that under the smoke exhaust mode of the longitudinal ventilation of the ignition tunnel and positive pressure ventilation in the non-ignition tunnel, in the case of a double-hole in an evacuation passage of quasi-rectangular tunnel, when the fire source is located at the evacuation passage, it can effectively prevent the smoke from entering the non-ignition tunnel.

1. Introduction

With the rapid development of urbanization, urban population and urban traffic are also growing rapidly. As one of the main ways of urban rail transit, the subway is considered to be an important means to solve increasingly crowded urban traffic problems. Among them, the quasi-rectangular shield tunnel technology is for intensive use of urban underground space, which saves 35% of underground space than the conventional circular shield machine, but causes the evacuation passage to have no space to set fire doors. On the other hand, the damage to the evacuation passage door of the tunnel communication passage will also cause a major liability safety accident[1]. Therefore, fire smoke control experiment research on the no evacuation passage door of the quasi-rectangular shield tunnel is not only to ensure the safety of the evacuation passage, but also to eliminate the installation of the evacuation passage door, which is of great significance for the interval tunnel fire control work [2].Based on the actual tunnel project, a 1:3 scale physical model is established. The smoke control adopts longitudinal ventilation in the ignition tunnel and positive pressure ventilation in the non-ignition tunnel to study the smoke control scheme when the fire is located in the evacuation passage.

2. Model Test Platform

2.1. Project General Situation

The lengths of the left and right lines of a quasi-rectangular tunnel in one city are 762.765m and 761.173m, respectively, and the cross-section size is about 11.5m*6.9m. The interval tunnel adopts a quasi-rectangular like section. According to GB/T 33668-2017[3], Evacuation passages should be set up between two underground single-line passenger operation sections. The distance between two adjacent evacuation passages should not be greater than 600 m. A fire door with two diaphragms in parallel and reverse opening should be set up in the passage. Therefore, an evacuation passage is provided in the interval tunnel and two door openings are opened in the evacuation passage, that is, a double-hole evacuation passage. The size of the one evacuation passage is about 0.9m*2.1m. The smoke control system in the tunnel adopts the smoke exhaust mode of longitudinal ventilation in the ignition tunnel and positive pressure ventilation in the non-ignition tunnel. According to the statistics of train fire heat release rate used in subway design in some countries and regions, it is shown that the range of fire heat release rate of subway train is 5 MW~10 MW.

2.2. Similarity criterion

At present, there are two main methods of tunnel fire research, experimental research and numerical simulation[4]. Due to the huge scale and large area of the tunnel, it is impossible to establish the overall test model. In order to obtain reliable research data, scale model test is proposed to carry out the research. The scale model test must ensure that the smoke flow of the model and prototype meets the similar conditions. Based on the similarity principle[5], the similarity criteria of the model test are deduced by using the similarity transformation method according to the differential control equation of smoke flow in tunnel fire. The Froude fire model with the model similarity scale of 1:3 is obtained[6,7]. The similarity criterion relations of the parameters of each physical quantity are shown in the Table 1.

Table 1. Contrast table of scale result of physical quantity

Parameter	**Scale factor（1:3）**
Physical Dimension（m）	0.33
Velocity（m/s）	0.577
Volume of Flow (m^3/s)	0.064
Pressure (Pa)	0.33
Temperature（℃）	1
Heat Release Rate of Fire Source（MW）	0.064

2.3. Test platform and Operating Condition Design

According to the similarity principle and the Froude similarity criterion [8], the scale model is established according to the 1:3 scale relationship. The cross-section size of quasi-rectangular tunnel is 3.5m*2m in width and height and 75m in length. An evacuation passage is set on the wall in the middle of the tunnel. The size of the evacuation passage outlet is 0.3m*0.7m. Considering the influence of trains, a train model with a length of 4m, a width of 1.25m and a height of 1m is made according to the size of underground trains. The scale of the fire source in the model ranges from 320kW to 640 kW. This experiment mainly studies the smoke exhaust mode of longitudinal ventilation in the ignition tunnel and positive pressure ventilation in the non-ignition tunnel when the fire source is located in the evacuation passage under the condition of one tunnel with a double-hole in an evacuation passage in tunnel. Under this ventilation mode, the smoke spread of fire and the feasibility of the smoke control scheme are studied. The schematic diagram of fire location and air distribution are shown in Figure 1.

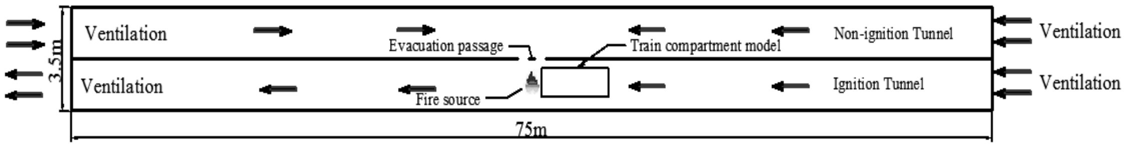


Figure 1. Schematic diagram of fire location and air distribution.

2.4. Layout of Test Equipment and Measuring Points

In order to observe and record the spread of smoke, video cameras are arranged at the evacuation passage entrance of the non-ignition tunnel and upstream of the fire source in the ignition tunnel. The method of weightlessness is used to measure Heat Release Rate of the fire source, that is, the electronic scale is placed below the fire source to measure the mass change of combustion material. Thermocouples T1~T9 and T10~T18 are respectively arranged in the ignition tunnel and the non-ignition tunnel ceiling, with a spacing of 7.5m. The schematic diagram of measurement points is shown in Figure 2.

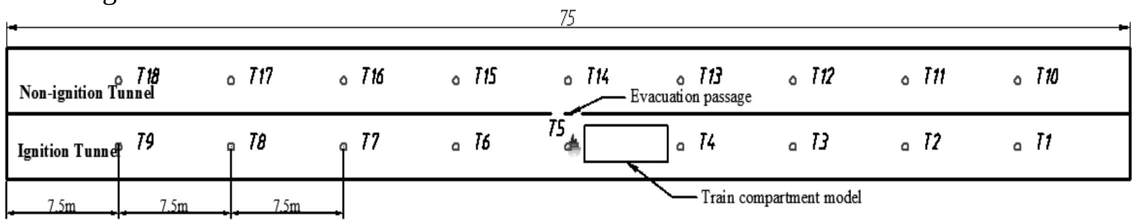


Figure 2. Schematic diagram of measurement points.

3. Analysis

3.1. Heat Release Rate of the Fire Source

The variation curve of heat release rate of the fire source is shown in Figure 3. The heat release rate increases rapidly after ignition, and increases first and then decreases with combustion. After ignition, with the combustion proceeding, the heat release rate of fire source gradually increases, and gradually stabilizes after 45s reaching 567 kW. Its fire growth coefficient is 0.13kW/s^2. The fire growth rate belongs to fast fire. By 70s, the heat release rate of the fire source reached a peak of 627 kW, then the heat release rate decreases gradually, and the combustion of 900s is basically ended.

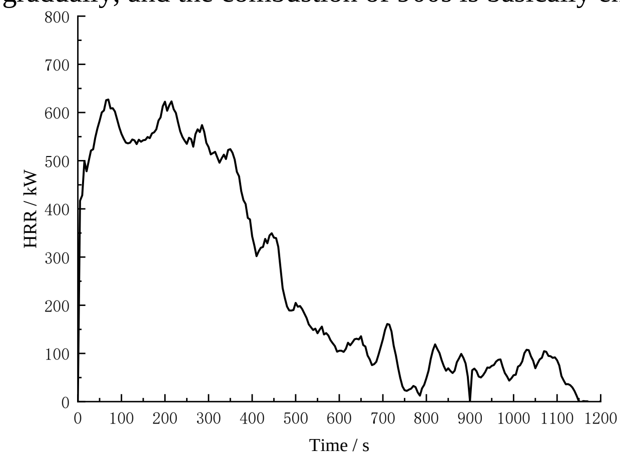


Figure3. Variation curve of heat release rate of the fire source.

3.2. Temperature Distribution of Ignition Tunnel

Figure 4 is the longitudinal temperature change Curve of the ignition tunnel. From Figure 4, when the tunnel fire occurs, the temperature of the tunnel rises rapidly. The maximum temperature of T5 is 130℃ at 80s, the maximum temperature of T6 is 82℃, and the highest temperature of T7 is 65℃. The measuring points upstream of the fire source increases at the initial time, and gradually returns to the environmental temperature after the smoke is effectively controlled.

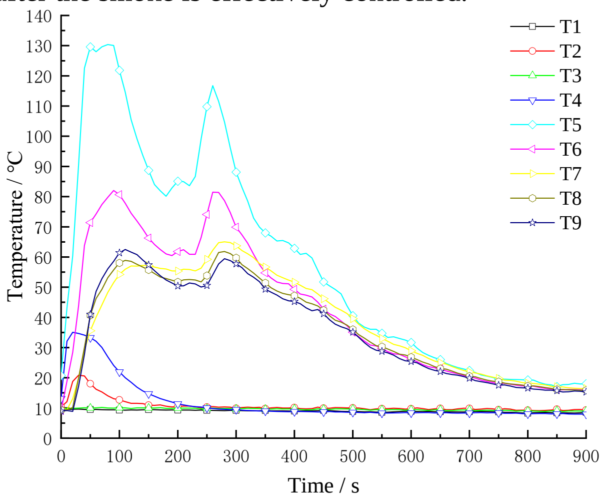


Figure4. Longitudinal Temperature change Curve of the ignition tunnel.

3.3. Temperature Distribution of the Non-ignition Tunnel

Figure 5 is the longitudinal temperature change curve of the non-ignition tunnel. As can be seen from Figure 5, when a tunnel fire occurs, except for the temperature near the exit of the evacuation passage rise was around 10°C, there is no obvious change in the other temperatures. After the smoke is effectively controlled, the temperature gradually returns to the ambient temperature.

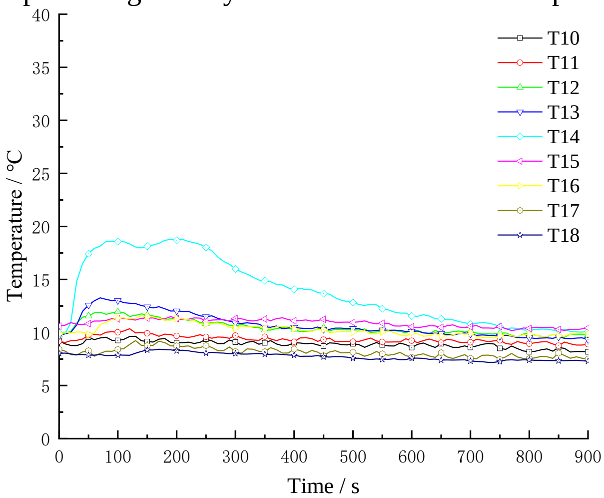


Figure5. Longitudinal temperature change curve of non-ignition tunnel.

3.4. Smoke Spread Phenomenon

The smoke spread phenomenon in the ignition tunnel is shown in Figure 6. It can be seen from the figure that after the fire occurs, obvious backflow of smoke was observed at 10s, that is, the ignition tunnel fan was started. The smoke reflux disappeared after 4min20s, and then the smoke no longer reflux. Figure 7 is the smoke spread phenomenon in the evacuation passage on the side of non-ignition tunnel. It can be seen from the graph that no smoke enters the non-ignition tunnel at the beginning of the evacuation passage after the fire occurs. After 10 seconds, the smoke enters the non-ignition tunnel through the evacuation passage, that is, starting the non-ignition tunnel fan. The smoke disappears at 1 minute. After that, the smoke can be effectively prevented from entering the non-ignition tunnel.

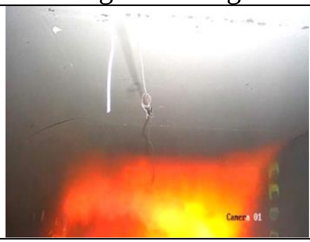
Ignition tunnel		
Time	10s	4min20s

Figure6. Smoke spread phenomenon in ignition tunnel.

Evacuation passage		
Time	10s	1min00s

Figure7. Smoke spread phenomenon in evacuation passage.

4. Conclusion

Through the experimental study on the smoke exhaust effect of longitudinal ventilation in the ignition tunnel and positive pressure ventilation in the non-ignition tunnel when the fire source is located at the evacuation passage with a double-hole in one evacuation passage in a quasi-rectangular tunnel, the following conclusions are obtained:

From the data of tunnel smoke spread and smoke control effect, it can be seen that when fire occurs at the evacuation passage entrance, the smoke exhaust mode of longitudinal ventilation in the ignition tunnel can effectively prevent the smoke backflow. When fire occurs at the evacuation passage entrance, the smoke exhaust mode of positive pressure ventilation is adopted in non-ignition tunnel, which can effectively prevent the smoke from entering non-ignition tunnel through evacuation entrance.

References

[1] Wang Y R. Liu Y, Zhu L, Li Y F. (2019) Canceling Fire Door in Cross-Passageway Based on Smoke Dynamic Simulation. J. Urban Rapid Rail Transit. 01: 86-92
[2] Xu Y, Mao J. (2008) Numerical Simulation for Optimization of Hybrid Fire Ventilation System in Highway Tunnel. In: International Conference on Bioinformatics & Biomedical Engineering. Shanghai. pp. 4000-4005.
[3] GB/T 33668—2017. Code for safety evacuation of metro[S]. Beijing: General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China, 2017.
[4] Xu P H. (2015) Research on Fire Characteristics and Smoke Control of Tunnel. D. Tianjin University of Commerce.
[5] Liu S T, Yang Y, Du L L. (2007) Subway fire model experiment similarity condition analysis. In: Fire Science and Engineering. Beijing. pp. 293-298.
[6] Wang F, Wang M. (2016) A computational study on effects of fire location on smoke movement in a road tunnel. J. Tunnelling & Underground Space Technology Incorporating Trenchless Technology Research, 51:405-413.

[7] Lee S R, Hong S R. (2006) A numerical study on smoke movement in longitudinal ventilation tunnel fires for different aspect ratio. J. Building & Environment, 41(6):719-725.
[8] Wu Y, Bakar M Z A. (2000) Control of smoke flow in tunnel fires using longitudinal ventilation systems-a study of the critical velocity. J. Fire Safety Journal, 35(4): 363-390