Influence of Different Number of the Open Exhaust Outlets in Tunnel Lateral Exhaust System on Smoke Exhaust Effect

Yang Huang¹, Li Zhang² and Xuefeng Han*

¹Nanjing Tech University, Nanjing, Jiangsu, 211800, China
²Nanjing Tech University, Nanjing, Jiangsu, 211800, China
*Xuefeng Han’s e-mail: safety@njtech.edu.cn

Abstract: In this paper, firstly, the parameters of the tunnel fire model are set up, the tunnel model is established, the reasonable grid is divided, and the appropriate fire power is selected. Secondly, the data of exhaust mode, layout position, exhaust power and wind speed of exhaust outlet of lateral exhaust system are selected reasonably. Finally, by using the FDS simulation software, the motion, visibility, smoke spreading distance and temperature of the tunnel fire smoke are simulated by changing the number of smoke vents opened in the lateral exhaust system under the same fire environment. The result of the simulation shows the number of open smoke outlets is 4 groups(upstream 1 group, downstream 3 groups), the smoke control effect is the best.

1. Introduction
The lateral smoke exhaust system has the advantages of high exhaust efficiency and little influence by the characteristics of the tunnel structure and the external environment[1]. The lateral exhaust system has a separate exhaust duct to allow the flue gas to be inhaled through the outlet, and the flue gas is discharged quickly and vertically from the exhaust flue, and it will not have a great impact on the diffusion of people from upstream and downstream of the fire source[2-4]. At present, most scholars focus on the vertical ventilation and top centralized exhaust system when they study the tunnel fire smoke control, but few on the lateral centralized exhaust system. Therefore, this paper considers to set a reasonable number of open smoke outlets at the lateral smoke exhaust system in the highway tunnel, so as to better block the spread of fire smoke and heat transfer in the tunnel.

2. Setting the model of fire in tunnel

2.1. The establishment of a geometric model
In order to simplify the model, this article has the following assumptions:

1) The tunnel model selected in this paper is 500m long, 14.55m wide and 7.1m high; on one side of the tunnel is provided with a separate flue, which is 500m long, 2.2m wide and 3m high; the fire source is located in the center of the tunnel 250m, in the middle of the tunnel, the entrance is on the left side, and the smoke exhaust passage is set above the driving direction lane side, so as to study the tunnel side. The influence of the number of smoke outlets in the smoke exhaust system on the smoke exhaust effect. The tunnel model is showed as Figure 1.
2.2. Setting the grid
This paper analyzes the fine sensitivity of the simulated grid. When the fire source is set in the middle of the tunnel, six groups of smoke vents are opened, the smoke exhaust volume is 160 m$^3$/s, and the wind speed is 1.5 m/s at one end of the tunnel. Based on the precision and computing time of computer, this paper selects the grid size of 0.4 m for subsequent simulation calculation, so as to reduce the simulation running time and improve the working efficiency. The single grid is 0.4 m × 0.4 m × 0.4 m.

2.3. Selection of tunnel fire source power
Heat Release Rate (HRR) is a parameter to characterize the size of the fire. The selection of HRR is based on a large number of studies by domestic and foreign experts in tunnel fires. Based on the investigation of highway tunnel fire, the fire power of tunnel fire simulation is set to 30 MW. In the numerical simulation of tunnel fire, the release rate of fire source usually remains steady state. To sum up, the fire source heat release rate in this paper is set to the steady state of 30 MW. The fire development rate grade is defined as ultra-fast fire. The corresponding fire development rate and the time required to reach the peak value of the fire are 0.1876 s, 399.89 s, the fire source area is 2 m × 2 m, the fire source center is the origin.

3. Setting of smoke outlet
From the viewpoint of practicability, engineering quantity and economy, this paper sets a group of electric smoke exhaust ports every 67.5 m on the exhaust flue, each group has three small smoke exhaust ports, the distance between single smoke exhaust ports is 2 m, the size is 1 m × 2 m, the height is 4.6 m. Heskestad plume model can be used to calculate axisymmetric smoke flow mass, and the smoke production rate of fire is 126.51 m$^3$/s. According to the relevant design manual and technical measures of the HVAC discipline, this paper proposes an additional 10%~20% air leakage in air duct system, the smoke emission is 160 m$^3$/s.
4. Effect of opening quantity of smoke outlet on smoke exhaust

In order to verify the effect of number of open smoke outlets on smoke exhaust effect, analyze selects 3, 4, 5 and 6 groups of number of open smoke outlets to establish models, and the working conditions are shown in Table 1:

| Working condition | Fire source scale (MW) | Number of open smoke outlets (Group) | Exhaust gas volume (m³/s) | Longitudinal ventilation wind speed (m/s) |
|-------------------|------------------------|--------------------------------------|---------------------------|------------------------------------------|
|                   |                        | Upstream | Downstream                     |                           |                                         |
| A1                | 30                     | 1        | 2                                | 160                       | 1.5                                      |
| A2                | 30                     | 1        | 3                                | 160                       | 1.5                                      |
| A3                | 30                     | 2        | 3                                | 160                       | 1.5                                      |
| A4                | 30                     | 3        | 3                                | 160                       | 1.5                                      |

With the increase of the number of smoke outlets opened, the spread distance of fire smoke in each working condition is increasing in the upstream and downstream. The smoke spread distance of working condition A3 and A4 is more than 300 m, which is not conducive to the safety evacuation.

4.1. The movement of the smoke after the end of the simulation when the number of the open exhaust outlets are different in the tunnel

Longitudinal distributions of temperature at the center of fire source under different conditions are showed as Figure 2.

![Figure 2](image_url)

4.2. Changes of temperature, smoke control range and visibility with time under different working conditions.

4.2.1. Temperature distribution

Figure 3 shows following temperature distribution at the tunnel ceiling and 2m height.
4.2.2. Smoke spread distance

Table 2 shows the smoke spread distance under various working conditions.

Table 2. Smoke spread distance in various working conditions

| Working condition | Fire scale / MW | Location of fire source | Number of open smoke outlets / group | Smoke discharge m³ / S | Ventilation wind speed m / S | Upstream spread distance / m | Downstream spread distance / m | Total spreading range / m |
|-------------------|----------------|-------------------------|-------------------------------------|------------------------|-----------------------------|-----------------------------|-----------------------------|--------------------------|
| A1                | 30             | Middle position of tunnel | 3                                   | 160                    | 1.5                         | 113                         | 168                         | 281                      |
| A2                | 30             | Middle position of tunnel | 4                                   | 160                    | 1.5                         | 117                         | 171                         | 288                      |
| A3                | 30             | Middle position of tunnel | 5                                   | 160                    | 1.5                         | 121                         | 182                         | 303                      |
| A4                | 30             | Middle position of tunnel | 6                                   | 160                    | 1.5                         | 133                         | 182                         | 315                      |

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4.2.3. Visibility

Figure 4 shows the changes of visibility under different working conditions.
5. Conclusion

This paper establishes a tunnel model to simulate the temperature changes, visibility and the movement of smoke in the tunnel over time. It shows that when the number of open smoke outlets is 3, it can not effectively release heat and eliminate smoke. When the number of smoke outlets is 5 and 6, the smoke spread distance is the longest. This is because when the number of openings is too more, the air disturbance and plume effect caused by the open smoke outlet make the distance of smoke spreading in the tunnel longer. It is concluded that four groups (one upstream group and three downstream groups) can achieve the best smoke exhaust effect.

Acknowledgements

Thanks for the financial support of the Nature Science Foundation of Jiangsu Province(Grant No. BK20161548); International cooperation project of Nanjing Tech University-Lund University, Sweden; The authors wish to thank teacher and group members for their kind support in this study.

References

[1] Qiu, Y. M. , Lou, B. , Xu, J. H. (2016) Numerical Simulation of Influence of Fire Source and Smoke Exhaust Vents Arrangement on Fire Smoke in Tunnels. Journal of Safety and Environment, 16(3): 51-55.

[2] Park, W. H. , Kim, D. H. , Chang, H. C. (2006) Numerical predictions of smoke movement in a subway station under ventilation. Tunnelling and Underground Space Technology, 21(3): 304-309.

[3] Zhang Li. Risk assessment of highway tunnel fire and smoke control of lateral smoke exhaust system [D]. Nanjing University of technology, 2019.
[4] Li Mingxuan, Li Le, Lu Guojian, et al. Experimental study on concentrated smoke exhaust in circular highway tunnel fire [J]. Fire science and technology, 2015, (01): 38-41.

[5] Cao Genren, Jiang Shuiping, Zhou Jian, Liu Shuai, Chen Jianzhong. Study on smoke flow law of side concentrated smoke exhaust mode in immersed tunnel [J]. Journal of China highway, 2018, 31 (01): 82-90.