Applied Mechanics and Materials *Online: 2012-11-29*
ISSN: 1662-7482, Vols. 226-228, pp 1472-1475
doi:10.4028/www.scientific.net/AMM.226-228.1472

Study of Fire Smoke Flow of Tunnel at Different Longitudinal Ventilation

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Keywords: Longitudinal ventilation, Tunnel fire, Smoke flow, Numerical simulation, FDS

Abstract. Once the tunnel fires happened, it will cause a major accident. And the smoke control of the runnel is important to fire prevention. A numerical simulation of the fire smoke flow in the tunnel model is presented by using FDS. The influence of different longitudinal ventilation on fire smoke flow of tunnel is obtained. And providing theory basis for tunnel ventilation system design, smoke spread control and safety evacuation. The results shown that in order to avoid reverse-flow and extend the time of smoke at the top of tunnel, the longitudinal speed should be controlled in 3.4 m/s; because of the role of longitudinal ventilation, smoke flow resistance and longitudinal ventilation generated by the effect of smoke flow resistance make the gas temperature first rise and then down.

Introduction

Along with the rapid development of tunnel engineering, more tunnel disasters occurred. Due to the characteristics of tunnel fire[1], such as spread rapidly, smoke exhaust difficultly and heat concentrated, once in fire, smoke spread rapidly to prevent the evacuation of people. And more than 80% of the casualties in the fire are caused by the toxic smoke inhalation[2], therefore, the smoke flow rule of different longitudinal ventilation is a significant part of designing the tunnel ventilation system, controlling the smoke spread and ensuring the safe evacuation.

In recent years, study of the tunnel fire has obtained some achievements[3,4]. Lu ping[5] analysis the changing relation between critical condition, critical velocity, tunnel wind speed, smoke flow velocity and fire intensity. Xie baochao[6] obtain the influence of different ventilation speed on the fire scale. According to the less literature about the influence of different ventilation conditions on the the smoke spread, this paper sets different conditions to study the regularity of distribution of the smoke, then in order to prove the validity of the paper, we compare experimental with numerical simulation results.

Smoke Motion Model

FDS Motion Model. FDS[7] (Fire Dynamics Simulator) is a field simulation program developed by NIST. The kinetic equations which used to describe the field simulation are mass conservation equation, energy conservation equation, momentum conservation equation, composition equation and state equation.

(1) mass conservation equation:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho u) = 0 \tag{1}$$

(2) energy conservation equation:

$$\frac{\partial}{\partial t}(\rho h) + \nabla \cdot (\rho h u) = \frac{Dp}{Dt} + \dot{q}^{m} - \nabla \cdot q \tag{2}$$

(3) momentum conservation equation:

$$\frac{\partial(\rho u)}{\partial t}+\nabla\cdot(\rho uu)+\nabla p=\rho g+\nabla\cdot\tau \qquad (3)$$

(4) composition equation:

$$\frac{\partial}{\partial t}(\rho Y_i)+\nabla\cdot(\rho Y_i u)=\nabla\cdot(\rho D_i\nabla Y_i)+\dot{m}_i^m \qquad (4)$$

(5) state equation:

$$p=\frac{\rho RT}{M}=\rho RT\sum_i(\frac{Y_i}{M_i}) \qquad (5)$$

FDS is an open process, and its accuracy is proved by the experiment, and the results of simulation resemble the real, therefore, we use FDS5 to simulate the conditions.

Physical Model. As shown in Fig. 1, this paper selects a section of Huainan tunnel, it measures 150m long, 10.8m wide and 8.1m height. At the midcourt line of tunnel, we set a fire measures 2m×2m×0.2m at x=60m.

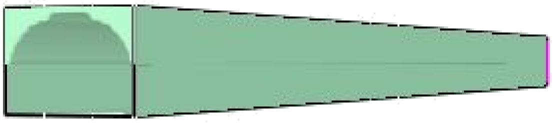


Fig. 1 Schematic diagram of the tunnel model

In order to study the rules of the fire smoke flow, we set monitoring points at 1m interval in the height of 1.8m of the tunnel center line. We spend 600s to simulate the conditions.

Working Conditions Setting

Boundary Conditions. According to Highway tunnel ventilation and lighting design standard[8](JTJ026.1-1999), and the tunnel fire belongs to oil fire, fire source has the heat release rate of 20MW[9]. The speed of tunnel entrances is ventilation wind speed, and the initial environmental temperature is 20℃, smokescope is 0. The relative pressure is 0Pa(local atmospheric pressure is 101325Pa)[10].

Working Conditions Setting. In order to study the influence of longitudinal ventilation on fire smoke flow, working conditions setting shows in the Table 1.

Table 1 Working conditions setting table

Working condition	Heat release rate[MW]	Ventilation speed[m/s]
1	20	0
2	20	2.8
3	20	3.4
4	20	4

Results and Discussions

Smoke Distribution Under Different Longitudinal Ventilation. Fig. 2(a) shows that when there is no longitudinal ventilation, because of the buoyancy, smoke will flow vertically to the vault, then spread to the up and downstream. Compared Fig. 2(b) with Fig. 2(c), we know that if the longitudinal ventilation is too small, the backflow is occurred; when the wind speed reachs 3.4m/s, smoke flow to the downstream only. But when the speed reachs 4m/s, turbulence occurred at the downstream, then can make smoke fallen to the ground early, this is not conducive to the safe evacuation. Therefore, in order to avoid the backflow and prolongs the time of smoke spreads to the front, we suggests that the wind speed of longitudinal should be control in 3.4m/s.

(a) V=0m/s

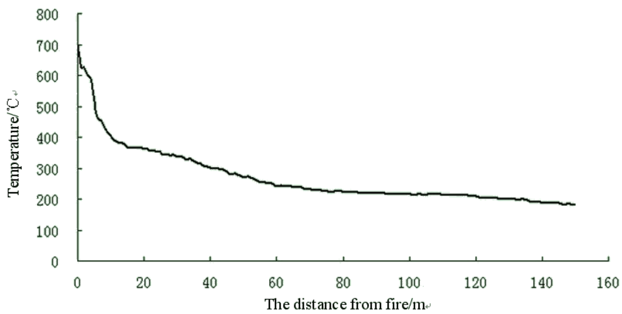
(b) V=2.8m/s

(c) V=3.4m/s

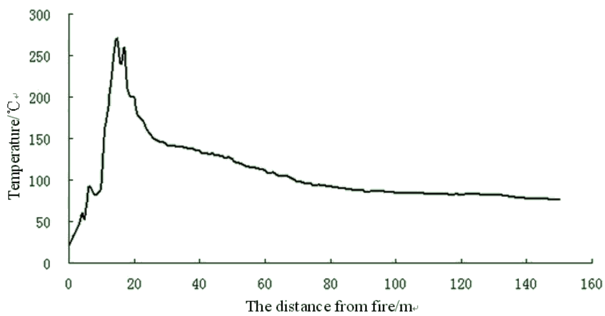
(d) V=4m/s

Fig. 2 Smoke distribution under different longitudinal ventilation

Distribution of Smoke Temperature. Fig. 3 shows the smoke temperature of 1.8m high along the tunnel length direction. From the simulation result, we know that the highest temperature is 600℃ under no ventilation. After adding longitudinal ventilation to the condition, hot smoke slanted by the wind, the highest temperature is located in downstream about 20m, and because of the heat exchange, temperature drops gradually. So, because of the smoke flow resistance and longitudinal ventilation caused by throttling effect, smoke temperature after rising to reduce.



(a) V=0m/s

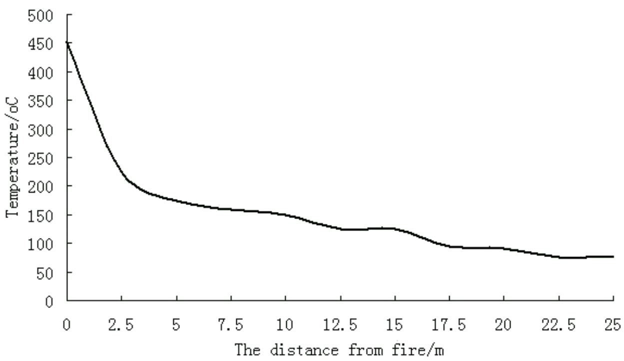


(b) V=3.4m/s

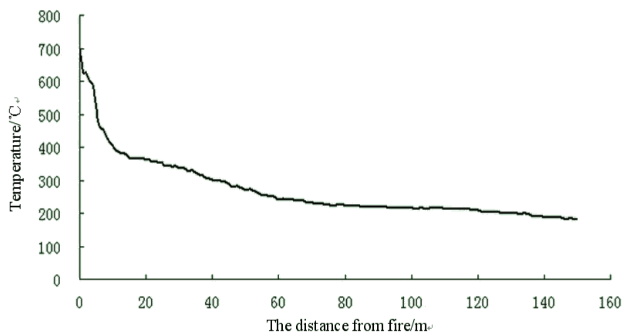
Fig. 3 Temperature distribution curve under different longitudinal speed

Result Comparison of Experiment and Simulation

Li hong set the tunnel model by reduced size proportion, it obtains the smoke temperature distribution cure of the no ventilation condition, the experiment condition is similar to this paper's condition. Comparing Fig. 4(a) with Fig. 4(b), because of the heat exchange, temperature drops gradually during the downstream, and we can know that the results are in good agreement with experimental data during the most stages of the fire. This means we can believe the simulation results in the foregoing discussions.



(a) Experiment results



(b) Simulation results

Fig. 4 Contrast figure of experiment and simulation

Conclusions

According to the simulation, we draw the conclusions as follows:

(1) In order to avoid the backflow and prolongs the time of smoke spreads to the front, we suggests that the wind speed of longitudinal should be control in 3.4m/s.

(2) Because of the smoke flow resistance and longitudinal ventilation caused by throttling effect, smoke temperature after rising to reduce, this provides the basis for safe evacuation.

(3) From the result comparison of experiment and simulation, we can know that the results are in good agreement with experimental data during the most stages of the fire. This means we can believe the simulation results in the foregoing discussions.

Acknowledgements

This work was financially supported by the China Postdoctoral Science Foundation(201003800).

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Vibration, Structural Engineering and Measurement II
10.4028/www.scientific.net/AMM.226-228

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