The Effect of Fire Location on Smoke Temperature in Tunnel Fires with Natural Ventilation

Zhongyuan Yuan, Bo Lei,*, Haiquan Bi
Southwest Jiaotong University, Chengdu 610031, China

Abstract

To investigate the effect of fire location on smoke temperature distributions in tunnel fires with natural ventilation, the 3-D numerical simulation model was developed using CFD code FDS. The previous works of 1/15 reduced-scale experiments were used to verify the simulation model. Then the effect of train location in tunnel, fire source location in fire carriage and fire carriage in train on tunnel ceiling temperatures were researched. The simulated results indicated that the train location in tunnel didn’t have significant effect on ceiling smoke temperatures when all of windows or doors are in the tunnel section containing fire source, but the ceiling smoke temperatures decreased when some windows or doors are beyond the boundary of tunnel section containing fire source. Moreover, the fire source location in fire carriage and the fire carriage in train didn’t have significant effect on ceiling smoke temperatures in the tunnel.

1. Introduction

The high temperature, high concentration of lethal toxic gases and low visibility caused by tunnel fire are very dangerous to passengers, constructions, equipment and so on in tunnel. So the fire safety is an important scheme in tunnel design [1]. To meet the requirement of evacuation of passengers during tunnel fires, the mechanical ventilation system often used in tunnel. In these two decades, using experiment or numerical simulation method, lots of research...
on the control of tunnel fires were conducted to understand the tunnel fire behavior under mechanical ventilation system [2,3].

To save the investment in ventilation equipment and operation costs of fans in the future, the natural ventilation system by setting openings at the top of tunnel can be used. Until now, the natural ventilation scheme has not been the subject of much of the research work. Using reduced-scale experiments, Kashef [4] investigated the effect of some parameters on ceiling temperatures in tunnel fires with natural ventilation.

In general the fire location is often considered in the centre of tunnel section between two neighbor shafts when the tunnel fires with natural ventilation were researched [5]. This is based on the point that the pressure imbalance at both side of fire source caused by fire location deviation from centre of the tunnel section could lead to the change of fire plume characteristic and hence introduce a better evacuation environment. However the pressure produced by fire plume maybe much stronger than the pressure difference caused by the pressure imbalance, so that the fire location deviation from centre of the tunnel section maybe couldn’t change the fire plume characteristic. Therefore, the fire location deviation from centre of the tunnel section maybe lead to a worse evacuation environment. In this paper the effects of fire location on smoke temperatures in tunnel fires with natural ventilation were investigated using numerical simulation method.

2. Simulation method

2.1. Physical and simulated model

The physical model in this research is a general double line subway tunnel with natural ventilation. The cross sectional size of tunnel is 9.3m×4.8m. The size of the train in tunnel is 120m×2.8m×2.7m and the length of a carriage is 20m. A series of natural ventilation shafts were set up on the tunnel ceiling to satisfy the normal ventilation or emergency ventilation requirement. In this research the shaft size is of 10×2.5×4 and the inner space between two neighbor shafts is 70m. According to the reduced-scale experimental research on tunnel fires with natural ventilation, the fire smoke can’t reach to the second natural ventilation shaft nearby fire source, so two shafts were set up on both side of fire source in simulated model in this paper. The fire source with the heat release rate of 10MW was assumed to appear in the carriage and the fire smoke flows from carriage to tunnel through the doors or windows. The schematic layout of physical and simulated model is showed as Fig. 1.

![Fig. 1. The layout of tunnel fires for (a) physical model; (b) simulated model.](image)

2.2. Mathematical model

Using the finite volume method [6], FDS solves numerically a form of N-S equations appropriate for low-speed, thermal-driven flow with an emphasis on smoke and heat transfer from fires. By means of the Smagorinsky form of LES (Large Eddy Simulation) is adopted to treat turbulence flow. When the Smagorinsky model is used in LES, three constant parameters such as Cs, Pr and Sc need to be confirmed. According to some studies in building fires [7], these three constant parameters are selected as 0.18, 0.2 and 0.5 respectively in this paper.
The combustion model used in this paper is based on mixture fraction concept. The mixture fraction is a conserved scalar quantity that is defined as the fraction of gas at a given point in the flow field that originates as fuel. The finite volume method is adopted to solve the radiation transport equation for a gray gas in FDS.

2.3. Boundary conditions

The ambient gas temperature and initial temperature of tunnel wall were set to be 25°C. The tunnel wall was made of concrete with the thickness of 0.5m and its conductivity, specific heat and density are 1.2W/m/K, 0.88KJ/kg/K and 2200kg/m³ respectively. The boundary condition of shaft or tunnel exits is set to be “OPEN”.

3. Results and discussions

3.1. The effect of train location in tunnel

The study of the effect of train location in tunnel on smoke temperature was conducted under the conditions that the fire source is in the centre of the fire carriage and the fire carriage is in the centre of the train. As shown in Fig. 2, to investigate the effect of train location in tunnel, three different train locations named from train location A to train location C were developed. Obviously the train locations A and B have a same property that all of doors and windows of fire carriage are in the fire section of the tunnel. The train locations C have another same characteristic that the some doors or windows are beyond the boundary of fire section of the tunnel.

![Fig. 2. The train location in tunnel for (a) train location A; (b) train location B; (c) train location C.](image)

The comparison of tunnel ceiling temperatures under these five different train locations is shown as Fig. 3. It can be found from Fig. 3 that the ceiling temperatures were almost the same for train location A and B in tunnel section containing fire source. However the ceiling temperatures in fire section of the tunnel were lower in train location C than that in those above two train locations. This is because that the natural ventilation shaft doesn’t have the effect on smoke flow characteristics from train to tunnel and hence have no effect on ceiling temperatures in tunnel fires with natural ventilation, when all of doors and windows of train are in the tunnel section containing fire source. However when the doors or windows were beyond the boundary of tunnel section containing fire source, the natural ventilation shaft have the significant effect on smoke flow characteristics from train to tunnel and hence lead to temperatures decrease.
3.2. The effect of fire source location in fire carriage

The study of the effect of fire source location in fire carriage was carried out under the train location C in tunnel and the fire carriage is in the centre of the train. As shown in Fig. 4, two different fire source locations in fire carriage were researched.

Fig. 4. The fire source location in fire carriage for (a) fire source location A; (b) fire source location B.

The effect of fire source location in fire carriage on the ceiling smoke temperature distributions are shown as Fig. 5. It can be observed from Fig. 5 that the ceiling smoke temperatures were almost the same for fire source location A and B in the tunnel. It indicates that the fire source location doesn’t have considerable effect on smoke flow characteristic from train to tunnel and hence doesn’t have significant effect on ceiling temperatures in fire section of the tunnel. The basic reason is that the initial smoke diffusion process is at above all the doors or windows at the fire starting in carriage.
3.3. The effect of fire carriage location in train

The study of the effect of fire carriage location in train was conducted under the train location C in tunnel and the fire source location B in fire carriage. As shown in Fig. 6, two different fire carriages location in train were investigated.

Fig. 6. The fire carriage in train for (a) fire carriage location A; (b) fire carriage location B.

The effect of fire carriage location in train on tunnel ceiling temperatures is shown as Fig. 7. It can be seen from Fig. 7 that the ceiling temperatures are almost the same in all the tunnel for these two fire carriage locations in train. The reason is that the smoke diffusion process is at above the train in tunnel, that is to say the train blockage doesn’t have significant effect on ceiling temperatures in tunnel fires with natural ventilation.

4. Conclusions

The 3-D numerical simulations were conducted using CFD program FDS to investigate the effect of fire location on smoke temperatures in tunnel fires with natural ventilation. The conclusions are as follows:

(1) The train location in tunnel didn’t have significant effect on ceiling smoke temperatures when all of windows or doors are in the tunnel section containing fire source, but the ceiling smoke temperatures decreased when some windows or doors are beyond the boundary of tunnel section containing fire source.

(2) The fire source location in fire carriage and the fire carriage in train didn’t have significant effect on ceiling smoke temperatures in the tunnel.
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