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Temperature Properties Simulation of Vehicle Fires in Large Cross-Section Road Tunnel

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ABSTRACT: As for large cross-section road tunnel with 15 m diameter, this paper analyzed temperature properties of vehicle fires. Based on CFD simulation method and the longitudinal ventilation velocity set as 3m/s, three intensities of fire source were considered during the discussion.

1 INTRODUCTION

Fire in road tunnels is an international and progressively serious problem. It is characterized by the danger it presents to the people affected, and in many cases by the considerable amount of material damage and structure failure, such as Mont Blanc tunnel fire and Tuoen tunnel fire happened in 1999(Kirkland, 2002; Leitner, 2001, Carvel et al., 2001; Yang, 1996). The high temperature caused by tunnel fire is the main reason that led to personnel casualties and property loss. In order to well understand fire phenomena in road tunnel and further effectively control such disasters, the temperature properties should be illustrated in detail. Numerical models based on CFD (Computational Fluid Dynamics) are becoming popular as predictive tools in road tunnel fire safety for describing the fire spread and the dispersion of fire products. They are mainly used to evaluate the impact of fire on environment due to accidental fire inside the tunnel. As for large cross-section road tunnel with diameter of 15m, this paper concerned the CFD analysis of vehicle fires. The longitudinal ventilation system was adopted and the ventilation velocity was set to be 3m/s. The corresponding simulation results of the temperature-time curves, maximum gas temperature as well as temperature field distribution were provided. Meanwhile, the suggestion for fire protection facility of road tunnel was also given out.

2 DESIGN OF FIRE SCENARIO FOR CFD

2.1 Brief Introduction of FDS

In these simulations, FDS (Fire Dynamics Simulator) 4.06 which was released by NIST(National Institute of Standards and Technology, USA) was used. FDS is a Computational Fluid Dynamics (CFD) model with LES(Large Eddy Simulation)of fire-driven fluid flow. The model solves numerically a form of the Navier-Stokes equations appropriate for low-speed, thermally-driven flow with an emphasis on smoke and heat transport from fires. The partial derivatives of the conservation equations of mass, momentum and energy are approximated as finite differences, and the solution is updated in time on a three-dimensional, rectilinear grid. Thermal radiation is computed using a finite volume technique on the same grid as the flow solver.

2.2 Simulation Scenario of Tunnel Fire

In this paper, the simulation length of the large cross-section road tunnel with diameter of 15m was 100m. The fire source was located at 37m from the upstream ventilation cross-section and 63m from the downstream ventilation cross-section, as shown in Fig.1 and Fig.2.

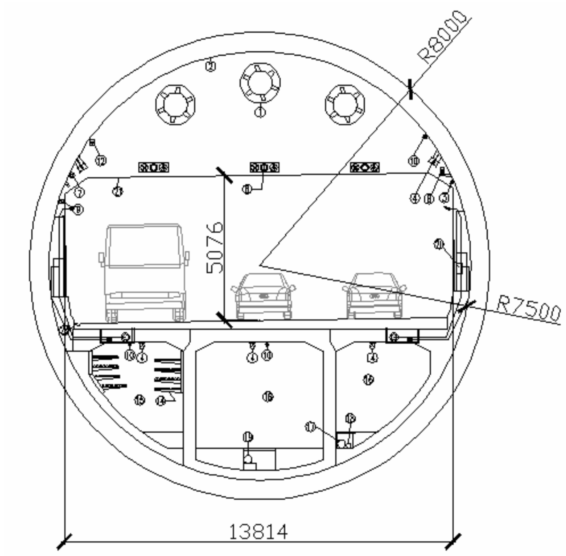

Fig.1 Cross-section of tunnel (mm)

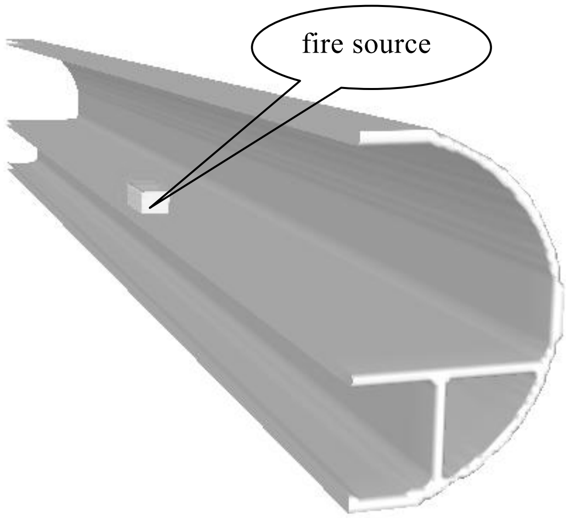

Fig.2 CFD simulation model

The Heat Release Rate(HRR) of fire source was based on the EUREKA project conclusion, which were completed by nine Europe countries in antiquated road tunnel. The HRR curve was shown in Fig.3(Haack, 1998;Gu and Cheng, 2003), including: (1) scenario 1: car; (2) scenario 2: passenger car/lorry; (3) scenario 3: heavy goods vehicle.

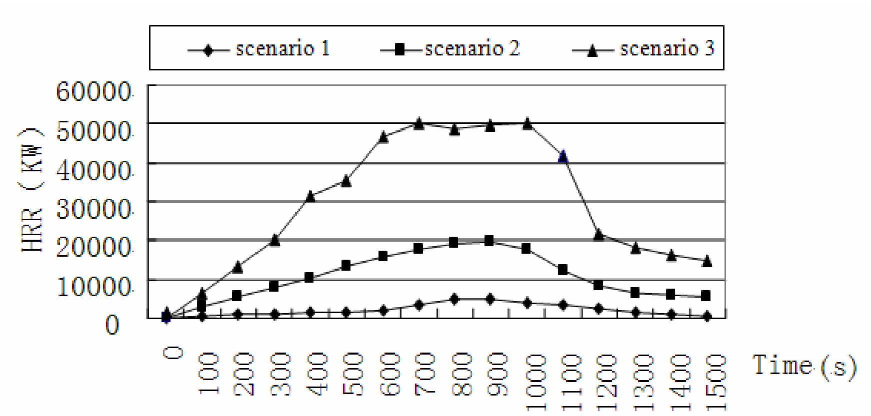

Fig.3 Heat Release Rate curve of fire scenario

3 RESULTS OF CFD SIMULATION

3.1 Temperature Distribution Feature in Tunnel Fire

As soon as the vehicle fire began to burn in the road tunnel during the simulation, the fire flame gradually enhanced, then one burning area was formed. Since the combustible material which participating in burning increased, the fire heat accumulated quickly and the temperature of smoke plume stream also rose at once.

During the simulation, the longitudinal ventilation velocity was set as 3m/s. The fire flames were sloped towards downstream. As for these three fire scenarios, the environmental temperature of the road tunnel reached the highest value at the position which was 5m downstream from the fire source, as shown in Fig.4. The maximum temperature value was concerned with combustible sorts, quantity of combustible material, burning time, burning speed as well as the geometry of the large cross-section tunnel.

Once the fire burnt, the environmental temperature increased very fast and did not follow the standard temperature-time curve. In general, the environmental temperature reached 80℃ in 5min and achieved its maximum value 15min later. Fig.5 illustrated temperatures of different positions in scenario 1, which were at 2.1m height above the road surface.

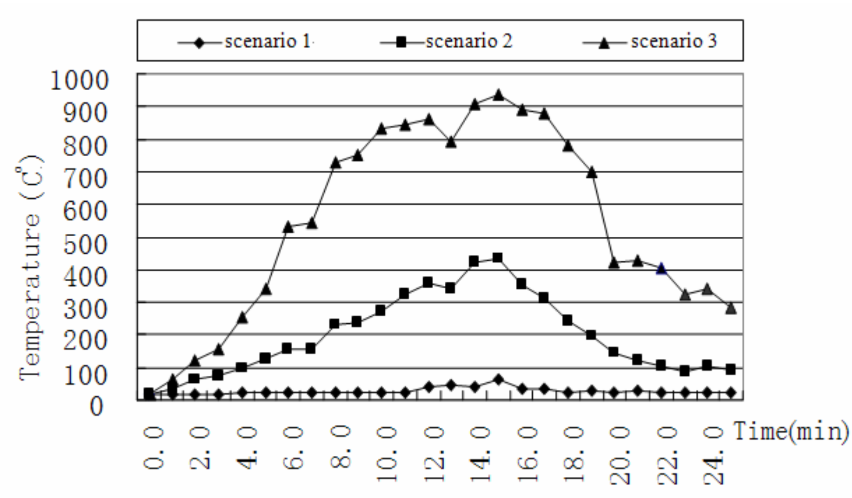

Fig.4 Temperature-time curve of the tunnel vault at the location of 5m downstream the fire source

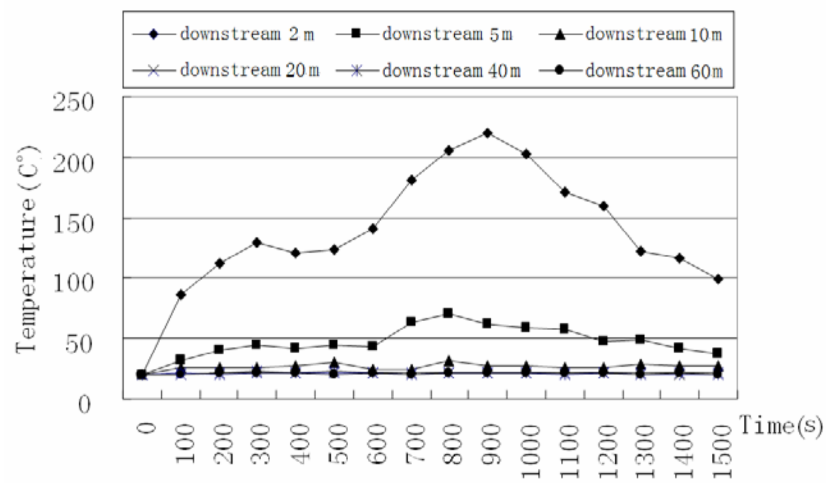

Fig.5 Temperature-time curve of the tunnel at 2.1m height downstream the fire source in scenario 1

3.2 Longitudinal Temperature Field Feature in Tunnel Fire

Since fire is a dynamic process, therefore, the longitudinal temperature field varies by time. The longitudinal ventilation velocity was set as 3m/s, the corresponding simulation results of longitudinal temperature field were given out respectively, the feature of vault position in scenario 3 shown in Fig.6 and the feature at the position of 2.1m height in scenario1 shown in Fig.7. It could be found that the temperature of different cross-sections increased gradually with the development of fire. When the temperature of fire source reached its peak value in about 10min, the temperature of other locations in the tunnel achieved maximum value separately. Later, the temperature gradually decreased by time. In the whole process, the temperature gradient of fire source was bigger than that of downstream area. The temperature gradient gradually grew down as the area being far away from the fire source.

In scenario 2, as the smoke spread into quasi steady state, the temperature distribution feature of longitudinal section at central position was shown in Fig.8. The temperature distribution was layered upstream from the fire source. Although the ventilation velocity was invariant, but influenced by flame disturbance and rising smoke fluid, the temperature distribution was not layered or clearly layered among the area from fire source nearby to the distance about 20m downstream. Since the smoke flew downstream and fully developed, the temperature distribution was distinctly layered downstream from the location which was 20m apart from the fire source.

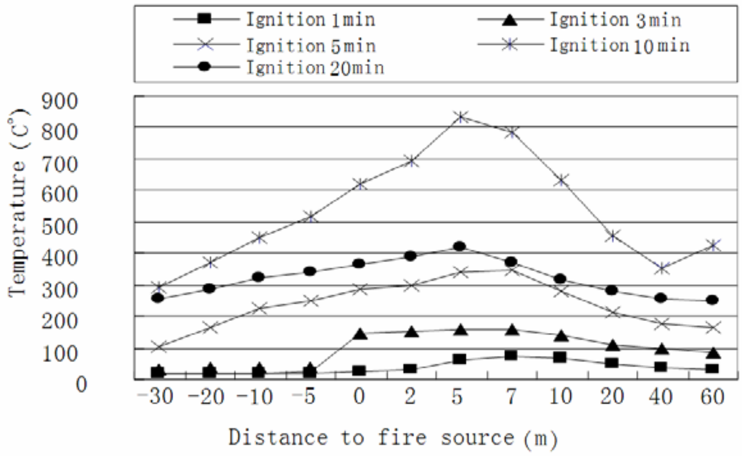

Fig.6 Longitudinal temperature simulation results of the tunnel vault in scenario 3

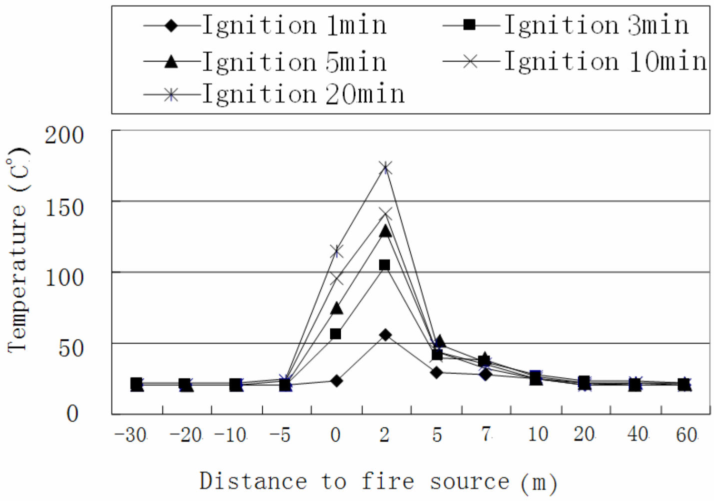

Fig.7 Longitudinal temperature simulation results of the tunnel at 2.1m height in scenario 1

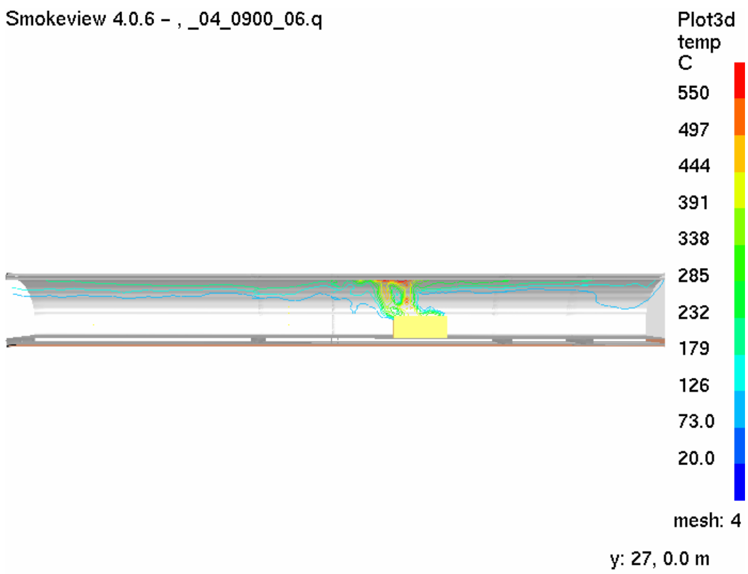

Fig.8 Longitudinal temperature simulation results of the tunnel at the central position in scenario 2 (℃)

3.3 Transverse Temperature Field Feature in Tunnel Fire

Since the longitudinal ventilation velocity was set as 3m/s, the fire flames were sloped downstream. In scenario 1, because the road surface was roasted by the fire, the temperature increased rapidly among the nearby area of the fire source. The corresponding transverse temperature distribution demonstrated that vault temperature is lower than that the bottom one. In scenario 2, the temperature at the central position of the cross-section was higher than that the vault and bottom respectively because of higher fire source intensity. As the location was far away from the fire source, it presented that the temperature decreased from the vault to the road surface because of the rising smoke fluid. Meanwhile, the temperature distribution of the cross-section tended to be homogeneous as the distance was away from the fire source. The transverse temperature distribution of different heights for these cross-sections in scenario 1 and 2 were shown in Fig.9 and Fig.10, while the simulation time was approaching 880s.

Based on the simulation results, in order to more effectively protect the large cross-section road tunnel against fire, the concrete lining and covering layer of reinforcing steel bar for the tunnel vault should be thickened or the fire resistance rating of the concrete should be enhanced. The other surface of the tunnel concrete could be protected by fireproof paint or fireproof panel. The fire detectors should be installed at least 4m height above the road surface so as to quickly monitor the fire.

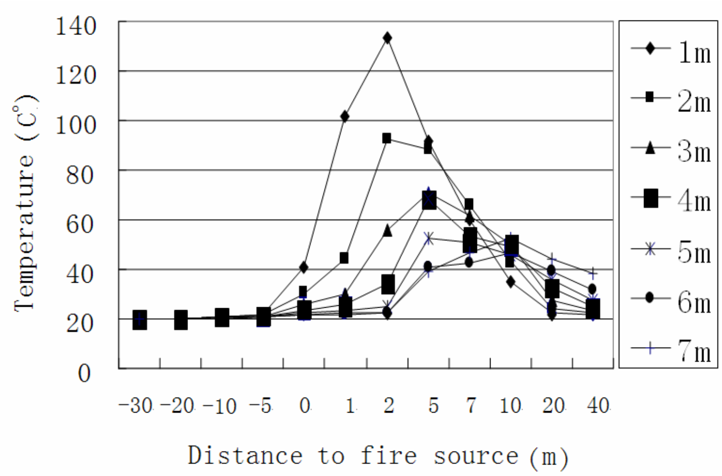

Fig.9 Transverse temperature simulation results of the tunnel for different cross-sections in scenario1

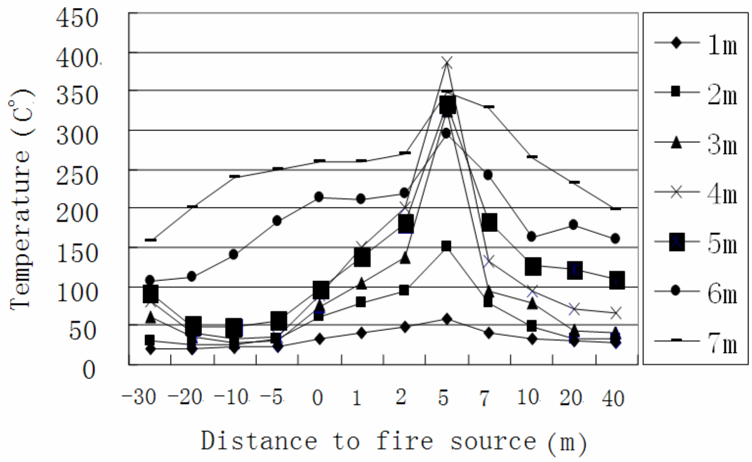

Fig.10 Transverse temperature simulation results of the tunnel for different cross-sections in scenario 2

3.4 The Diffusion Scope of Temperature Field in the Tunnel Fire

While the longitudinal ventilation velocity was set as 3m/s, the diffusion scope of temperature field expanded as the fire source intensity increased. For example, taking the temperature of 80℃, as for the position of 2.1m height, the diffusion scope of temperature field was from 1.6m to 5.8m in scenario 1 and that was from 1.0m to 7.0m in scenario 2. The simulation results were shown in Fig.9 and Fig.10.

4 CONCLUSION

(1) As the longitudinal ventilation velocity was set as 3m/s, the larger the fire intensity, the higher the temperature in tunnel fire.
(2) As the longitudinal ventilation velocity was set as 3m/s, the larger the fire intensity, the larger the diffusion scope of temperature field in tunnel fire.
(3) The environmental temperature increased rapidly in tunnel fire. In general, the temperature reached 80℃ in 2 to 10min after the fire began to burn and achieved its maximum value in about 15min.
(4) As the longitudinal ventilation velocity was set as 3m/s, the longitudinal temperature field feature in tunnel fire demonstrated that the temperature among the fire source region was higher than other area. The temperature decreased as the distance away from the fire source.
(5) As the longitudinal ventilation velocity was set as 3m/s, the transverse temperature field distribution feature changed with the value of fire source intensity.
(6) The diffusion speed of temperature field at the vault was faster than that the 2.1m height in tunnel fire.

ACKNOWLEDGMENTS

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