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Experimental study of smoke spread in titled urban traffic tunnels fires

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Abstract

More and more urban traffic tunnels are built due to the heavy traffic in dense urban areas. Fire safety in tunnels is a concern due to the large traffic flow. Most of the urban tunnels have slope. Knowledge on smoke spread in titled tunnel is still limited. Experimental studies on the smoke spread in a titled tunnel are carried out by the reduced-scale tunnel model tests and will be discussed in this paper. Effects of the titled gradients and longitudinal ventilation speed on the temperature distribution and smoke stratification downstream from the fire along the tunnel will be studied The results show that the smoke spread upwards much faster with the slop gradient increasing, and a thick smoke layer was formed when smoke moved to the upward part of the tunnel and filled it up. The ventilation speed had a great influence on temperature distribution along the tunnel, and the smoke stratification will be distributed when the longitudinal ventilation speed becomes large. Lower ventilation speed should be adopted at the beginning to ensure the smoke downstream of the fire keep stratified to give the tunnel users more time to escape.

Keywords: urban traffic tunnel; reduced-scale model; smoke spread

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1. Introduction

In order to mitigate the traffic congestion problems, more and more urban traffic tunnels have been and will be constructed due to the heavy traffic in dense urban areas in China in recent years. Comparing with other kinds of tunnels, traffic in urban tunnels may have larger traffic volumes due to its special site. Fire accidents may occur due to the collision of the cars, the engine overheating, the mechanical or electrical failure, etc. Fire safety in these kinds of tunnels is becoming a major issue following the catastrophic losses experienced in the Mont Blanc tunnel fire in 1999 and the Gotthard tunnel fire in 2001. Consequences of a tunnel fire can be very serious, which might lead to tragic injuries and fatalities, considerable infrastructural damage, loss of income due to the breakdown in operation and loss of public confidence in the use of road tunnels. Due to the confined conditions, such fires can be more severe, in terms of rate of growth and temperature, than that in the open field[1-2].

To assess the hazards arising from tunnel fires and draw some effective mitigation strategies, fully understand the smoke and heat propagation in tunnels is necessary. Most of our knowledge about smoke and fire spread in tunnels has generally been obtained from large scale testing. Large scale testing is expensive, time consuming and logistically complicated to perform. The information obtained is often incomplete due to the limited number of tests and the limited instrumentation. However, large scale testing is necessary in order to obtain acceptable verification of results in a realistic scale. Reduced-

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scale tests can be used as a complement to large scale testing. They can provide information which is difficult to obtain otherwise as their relatively low cost allows for parameter studies[3-4].

The Urban traffic tunnel always having slopes comparing with other kinds of tunnels, and the slope would influence the smoke spread greatly due to the stack effect. Although there were a lot of works having been done on studying the smoke spread in tilted tunnels by experimental or numerical method[5-8], smoke movement pattern in these kind of tilted tunnels is not fully understood, further studies are needed[9]. The smoke spread and temperature distribution in tunnels with different slop gradients under different longitudinal ventilation velocities would be studied by the reduced-scale model tests in this paper, the results would be reported.

2. Scale model test

A 1/6 scale tunnel model with rectangular cross section was constructed by the fire glasses boards, and the model tunnel itself is 6 m long, 1.5m wide, and 1.3m high, as shown in Fig. 1. Similarity rules impose a strict conservation of Froude number so that, for a geometrical reduction factor α, velocities are given in the scale $\alpha^{1/2}$ and both flow rates and heat release rates are scaled according to $\alpha^{5/2}$[10]. Different titled gradients of 0, 3% and 5% were built by raising the one end of the model tunnel. Smoke spread in these three tunnels would be studied respectively.

Longitudinal ventilation was achieved by driving inlet air flow by a fan at one end. The rotational speed, and thereby the capacity, could be controlled using an electrical device coupled to the motor. Longitudinal ventilation velocities of 0m/s、0.6 m/s、0.9 m/s and 1.2 m/s are used in the test series.

Fig. 1. Scale model tunnel.

The fire source was a 0.3m × 0.3m (L × W) porous bed burner with its top surface set flush with the tunnel floor, LPG was used as fuel, metered through a rotameter. Fire sizes of 57 kW was produced by changing the flow rate of the LPG respectively in the experiments, these fire sizes correspond to fires of approximately 5 MW when the scaling procedure was applied. They thus represent typical vehicle fire sizes in urban traffic tunnel[11]. The burner is located at the center of the tunnel, 0.3m away from the tunnel entrance, as shown in Fig. 2.

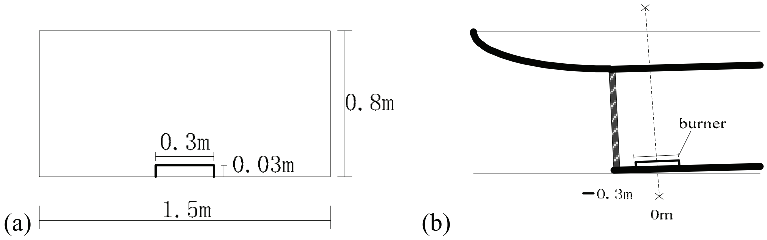


Fig. 2. Location of the fire source.

Thermocouple trees (K-type) distributions in longitudinal direction along the tunnel were shown in Fig. 3, and vertical distributions of thermocouples in one thermocouple tree were also shown in Fig. 3, measuring the temperatures at the relative positions.

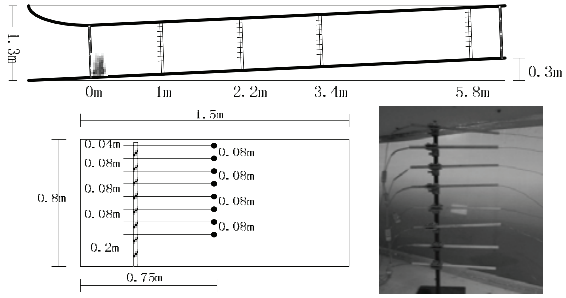


Fig. 3. Distribution of the thermocouples.

3. Results and discussions

Vertical temperature distributions at different height above the tunnel floor at the centerline of the tunnel and longitudinal temperature distributions along the tunnel under different longitudinal ventilation velocities and different inclined gradient for fire size of 60 kW were shown in Figs. 4, 5 and 6 respectively. It can be found that the temperature of the smoke is higher at the zone close to the fire source, and it will be cooling down when it propagates along the tunnel due to the combined effects of the convective heat exchange with walls and mixing between the smoke the fresh air layer. The smoke stratification is found clearly along the tunnel with no ventilation. With the longitudinal ventilation speed increasing, temperature at the higher position above the tunnel floor would decrease due to the flame deflected by the wind, hot smoke will spread at the lower level, this lead to the longitudinal temperature gradients become small, and temperature at the zone far away from the fire source would increase. At the mean time, the vertical temperature gradients were also found to be reduced along the tunnel, this means that the stratified smoke would be disturbed. This might be dangerous for the tunnel users at downstream of the fire, they need to pass through the hot smoke layer to escape from the tunnel. With the gradient of the slop becoming large, higher temperature would be found at the downstream from the fire, another factor the main factor to hot smoke is found to spread much faster to the top exit than that in the level tunnel. This might be dangerous for the occupant’s evacuation.

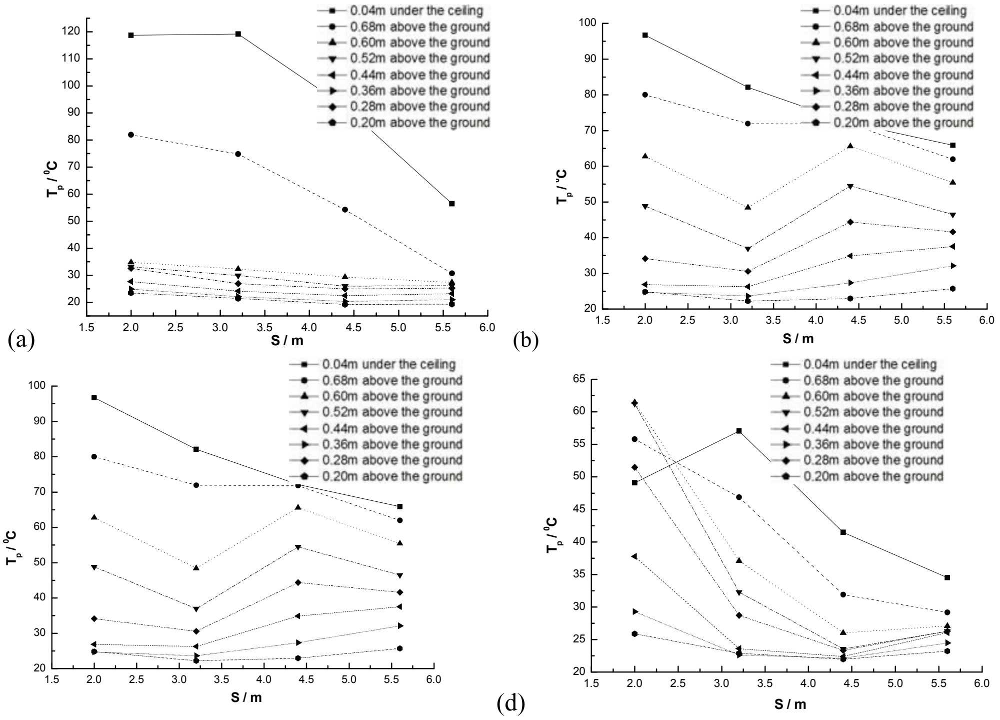


Fig. 4. Temperature distributions along the tunnel under different longitudinal ventilation velocities (level tunnel) of (a) v = 0m/s (b) v =0.6m/s, (c) v =0.9m/s and (d) v =1.2m/s.

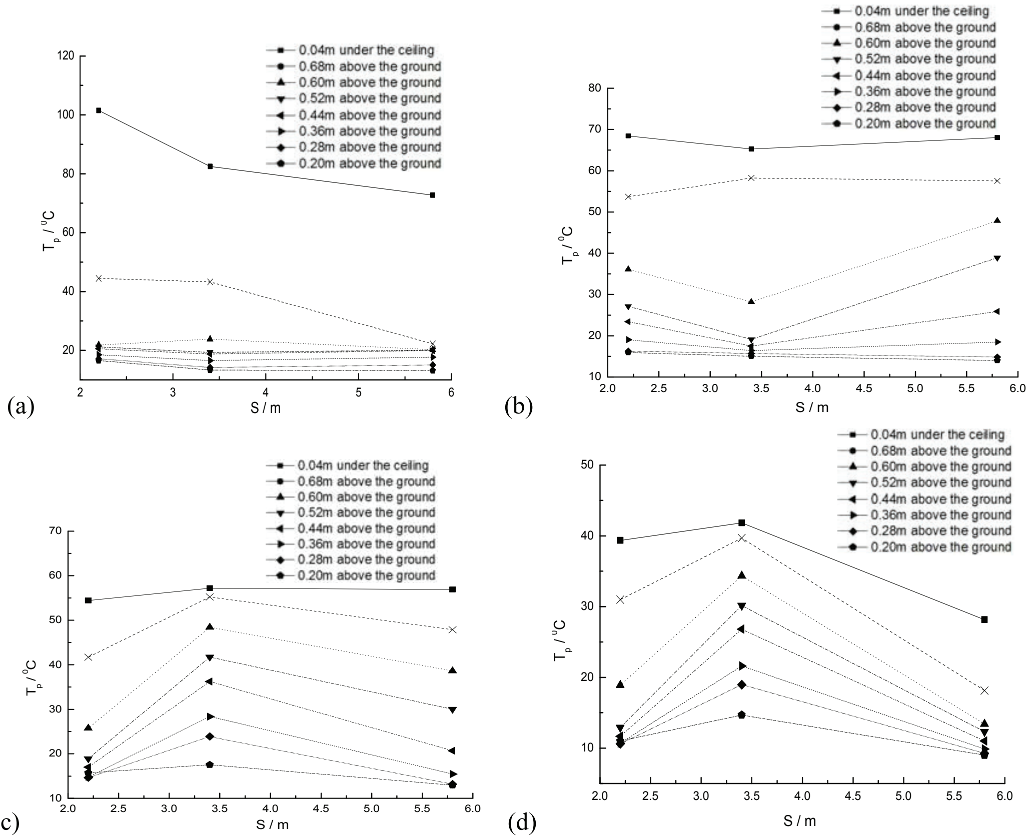
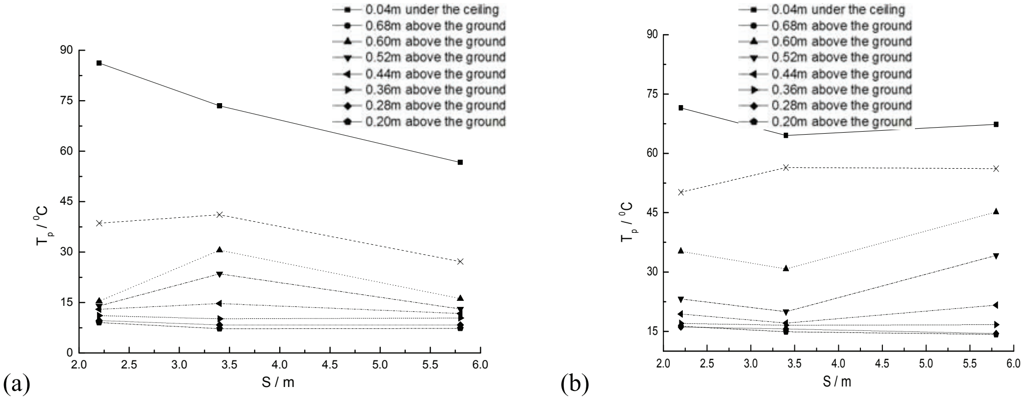
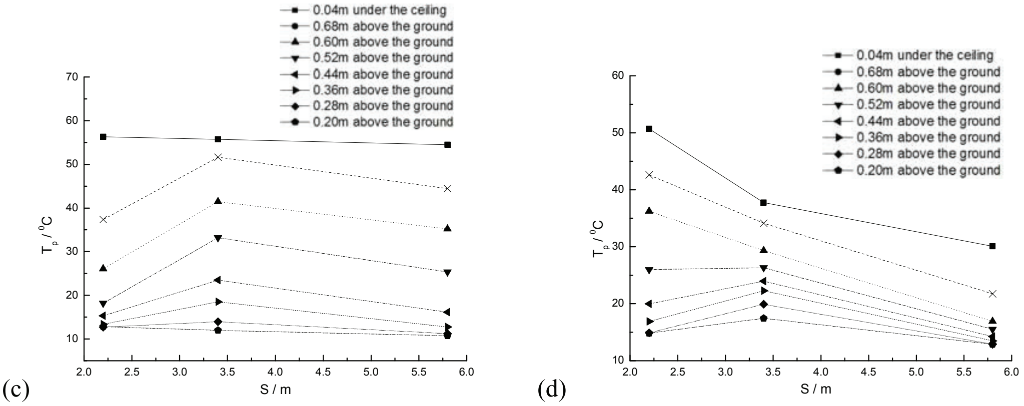


Fig. 5. Temperature distributions along the tunnel under different longitudinal ventilation velocities (tunnel slope = 3%) of (a) v = 0m/s (b) v =0.6m/s, (c) v =0.9m/s and (d) v =1.2m/s.





(c) (d)

Fig. 6. Temperature distributions along the tunnel under different longitudinal ventilation velocities (tunnel slope = 5%) of (a) v = 0m/s (b) v =0.6m/s, (c) v =0.9m/s and (d) v =1.2m/s.

4. Conclusions

The smoke spread in a titled tunnel with different titled gradients under different longitudinal velocity is studied by the reduced-scale model test in this paper. The results show that hot smoke spread much faster to the top exit due to the stack effect in a titled tunnel than in the level one, and a thick smoke layer is formed when smoke moved to the upward part of the tunnel and filled it up. This will be dangerous for the occupant's escaping. Some special smoke control measures should be taken when the fire occurs in a tunnel with slope. The ventilation speed is found to have a great influence on temperature distribution along the tunnel, maximum temperature in tunnel due to the fire would be reduced, and the smoke stratification would be distributed when the longitudinal ventilation speed becomes large. Lower ventilation speed should be adopted at the beginning to ensure the smoke downstream of the fire keep stratified to give the tunnel users more time to escape. The results might be useful for the smoke control design and operation in these kinds of tunnels.

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