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The impact of altitude effect on tunnel fire characteristics

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Tunnel fire can not only lead to huge damages to economic losses, but also threats the human safety. Nowadays, more and more tunnels are established on plateau, and there are some differences between tunnel fire in plateau and in plain. Little research has been made about the impact of altitude on tunnel fire, so this paper is concentrated on this topic. CFD (Computational Fluid Dynamics) technology develops rapidly, very many scholars use it in study and the accuracy of the simulation results has been certified. In this background, the technology was applied to study the impact of altitude on tunnel fire. Comparing simulation results at different altitude, some differences were found. Temperature at axle wire of the tunnel is much higher and the high temperature area is bigger at higher altitude than at lower altitude ceiling temperature magnifies with the rising of altitude. Ceiling temperature decays in an exponential model no matter at high or low altitude. The coefficient *k* increases because of the rising of altitude, meaning that ceiling temperature decays faster at higher altitude. The smoke diffusion length at 100 s told that smoke diffusion velocity is bigger at higher altitude, so the same distance from fire source, the higher altitude will be into danger faster. The smoke diffusion length at 100 s told that smoke diffusion velocity is bigger at higher altitude, so the same distance from fire source, the higher altitude will be into danger faster. All these factors indicate that when HRR is same, the higher altitude, the bigger danger. To some extent, a conclusion can be made that altitude rising can aggravate the consequence of the tunnel fire, and more attention should be paid to high altitude tunnel fire.

Keywords: tunnel fire, altitude, temperature, smoke diffusion, CFD simulation

INTRODUCTION

Tunnel fire can cause disasters. In 1999, a shocking fire accident happened in Mont-Blanc road tunnel, made 39 deaths, 43 cars ruined and traffic interruption for a year and a half [1]; in 2008, DaBao Mountains tunnel fire in China made 2 death, 5 injured, 2 trucks ruined, and traffic interruption for a month.

Tunnel fire safety has attracted many experts' interests, they made lots studies, many literatures have been reported about the maximum smoke temperature under ceiling [2,3], smoke temperature longitudinal distribution in a tunnel fire [4, 5], and ventilation effect on fire development[6]. Almost all these researches only considered standard pressure atmosphere (altitude is about 100 m)..

Recently, due to the Western China, many tunnels created for transportation at high altitude places, such as QiLian Mountains tunnel at an altitude of 3700 m,BaLang Mountains tunnel at an altitude of 3800 m, Queer Mountains tunnel at an altitude of 4300 m. Variations in altitude make changes in environment, further greatly influence tunnel fire characteristics. So the study of the impact of altitude to tunnel fire has practical significance

Nowadays altitude effects on fire have attracted some researchers' attention. Y. Zhang [7-9]carried out a series of comparative laboratory-scale experiments to study on the characteristics of horizontal flame spread on plateau, and found that the flame spread rate on plateau is lower and the altitude difference can change the pyrolysis mechanisms; Niu Yi [10] conducted fire experiments of cardboard boxes filled with shredded office paper to study the difference of solid fuel fire characteristics at different altitudes, found that mass loss and flame axis temperature changed with the pressure changing. F. Tang and L.H. Hu [11] did numerical CFD simulations of CO concentration distributions in a reduced pressure atmosphere with lower air entrainment at high altitude, made the conclusion that longitudinal decay profiles of CO concentration are similar in different pressure and the smoke flow temperature decays faster with distance along the tunnel in the reduced pressure atmosphere

NUMERICAL SIMULATION

CFD brief introduction

CFDis a product of modern hydromechanics, mathematics and computer science. FDS is one of CFD, specialized in fire simulation, based on mass

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conservation equation, energy conservation equation, momentum conservation equation and species conservation equation, and it was, is, and will be used to compute the fire behaviors widely. Previous works have already proved the simulation results' accuracy. So this paper will use FDS to simulate tunnel fire under different atmosphere

Simulation model

This paper uses the Chinese typical single hole bi-directional tunnel as the simulation physical model. The simulation section is 300 m long,10 m wide and 7 m high, seeing as an rectangle, fire source is in the center of the tunnel, simulation model is presented in Fig 1. In this paper, X (0~150) is the direction of the length, Y(0~10) is the direction of the width, Z(0~7) is the direction of the height.

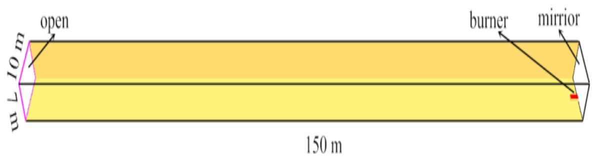

Fig.1. Simulation model.

In order to study the impact of altitude to tunnel fire characters, some parameters are varied in simulation, as Table 1..

Grid is a key issue for the accuracy of simulation results. It is related to the HRR and the environment parameters. The specialists and scholars have found the division of the grid should refer to the formula.

$$D^* = \left(\frac{Q}{\rho_\infty c_p T_\infty \sqrt{g}}\right)^{\frac{2}{5}} \quad (1)$$

where $D^*$is fire source characteristic diameter, m; $Q$is heat release rate, KW; $\tilde{n}_\infty$ is the density of air, kg/m^3; C_p is specific heat of environment, kJ/kg•K;$T_\infty$is the temperature of environment, K; g is the gravitational acceleration, m/s^2.

Table 1. The parameters at different altitude

	NO.1	NO.2	NO3	NO.4	NO.5
EGL[m]	0	1000	2000	3000	4000
Pressure[KPa]	101.3	89.6	79.3	70	61
Temperature[K]	298.5	292.5	286.5	280.5	274.5
Air density[kg/m^3]	1.208	40	30	20	10

The cell size should not be larger than 0.1~0.2 D^*, D^* changed with the altitude. A truck's heat release rate is about 30 MW, so consider heat release rate in the simulation as 30 MW. The largest cell size (ä) responds to different altitude shows in Table 2.

Table 2. The largest cell size in different altitude

	0	1000	2000	3000	4000
D*[m]	3.25	3.30	3.51	3.76	4.06
ä [m]	0.65	0.66	0.702	0.752	0.812

According to table 2, the cell size is designed to be 0.5 m×0.5 m×0.5 m.

Devices and slices

There are some key issues for tunnel fire: temperature and smoke. High temperature not merely damages the tunnel construction but also causes a big harm to people lives. In order to study the temperature distribution, a temperature slice should be set up at the center line (Y=5 m). To learn the ceiling temperature, a series of thermocouples should be installed below the ceiling (Z=6.5 m, Z=6 m respectively) at one section, and every 25 m should be installed one series of thermocouples. Smoke contains a lot of toxic gas, so it can asphyxiate people and make them oxygen-starved, it is the chief reason for human death in a tunnel fire. To analysis smoke characteristics, smoke output must be set as one of the output

RESULTS AND DISCUSSIONS

The altitude effect on smoke diffusion

Smoke diffusion characters is very significant for tunnel fire analysis. Fig.2 demonstrates smoke diffusion length at time of 100 s. It can be seen clearly that smoke diffusion length extends when the altitude rising. This phenomenon shows that the diffusion velocity magnifies along with the increasing of altitude. The main reason is the more smoke is produced at high altitude when HRR is same. Because the area which is at the same distance from fire source will be into danger faster at higher altitude, and the bigger region is influenced by smoke, the tunnel fire in high altitude may result in huger losses.

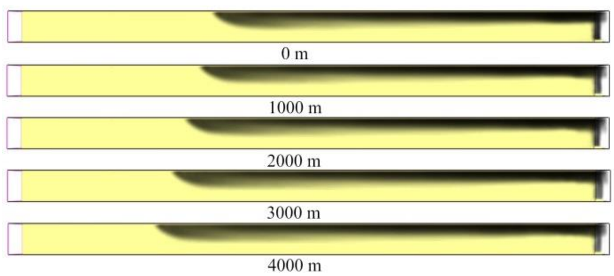

Fig. 2. Smoke diffusion length at T=100s

The altitude effect on temperature

Temperature is another important factor to analysis. Figure.3 shows temperature distribution at Y = 5 m. It's apparent the high temperature area is getting bigger when the altitude gets higher, and so is the maximum temperature increment near the fire source. It is consistent with smoke diffusion, tells that altitude can cause more serious temperature damage when HRR is same.

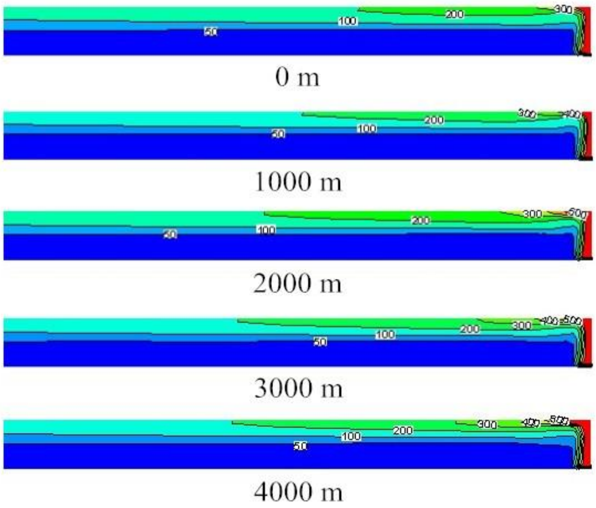

Fig. 3. Ceiling temperature distribution

Hu et al. [2] has found that ceiling temperature decays in an exponential model along the tunnel. The formula is as follows.

$$\frac{\Delta T_x}{\Delta T_0} = e^{-k(x-x_0)} \quad , (2)$$

where ÄT_x is the rising of temperature at the distance x m from fire source, Ä$T_0$is the reference rising temperature, meaning the rising temperature at the reference distance, *x* means the distance form fire, x_0 is the reference distance from fire source

Table 3. Fit coefficient for temperature distribution=

Altitude (m)	0	1000	2000	3000	4000
k	0.0078	0.0085	0.0091	0.0096	0.0103
R	0.9985	0.9958	0.9966	0.9927	0.9946

The ceiling temperature rising at the distance 25 m from fire source as the reference temperature, by using origin software, the fitting formula at different altitude is made respectively, as Fig.4 and Tab.3 represents. The correlation coefficients R at different altitude are all above 0.99, so it certifies that ceiling temperature decays along the tunnel by power exponent no matter at high altitude or at low altitude. And it is seen that k increases as the increasing of altitude, it demonstrates that altitude rising will lead ceiling temperature decrease faster.

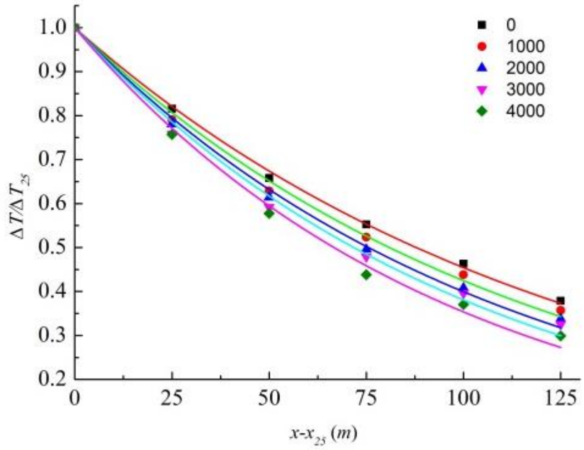

Fig. 4. Ceiling temperature decays fitting model.

CONCLUSION

Altitude effect has great impacts on tunnel fire. Smoke diffusion length is longer when altitude is higher and the diffusion velocity grows with the increase of altitude. The highest temperature under ceiling is bigger too and so is the higher temperature area. Ceiling temperature decays along the tunnel by power exponent no matter at high altitude or at low altitude, the fit coefficient increases with the increasing of altitude.

Both the smoke diffusion characters and the temperature distribution tell that when the altitude is higher, the danger is bigger, the time for people rescuing is less and the loss may be greater.

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REFERENCES

1. L. Barbato, F. Cascetta M. Musto, *Tunnelling and Underground Space Technology*, **43**, 253 (2014).
2. L. H. Hu, R. Huo, W. Peng, *Tunnelling and Underground Space Technology*, **21**, 650 (2006)
3. H. Kurioka, Y. Oka, H. Satoh, *Fire Safety*, **38**, 319 (2003).
4. J. P. Kunsch, *Fire Safety Journal*, **37**, 67 (2002)..
5. P. Z. Gao, S.L. Liu, W.K. Chow, *Tunnelling and Underground Space Technology*, **19,** 577 (2004).
6. R.O Carvel, A.N. Beard, P.W. Jowitt, *Tunnelling and Underground Space Technology*, **16**(1), 3 (2006).
7. Y. Zhang, J. Ji, J. Li, *Fire Safety*, **51**, 120 (2012).
8. Y. Zhang, X. Huang, Q. Wang, *J. Hazard.Mater.*, **189**, 34 (2011)..
9. Y. Zhang, J. Ji, X. Huang, *Chinese Sci. Bull.*, **56**, 919 (2011)

10. N. Yi, H. Yaping, H. Xiaokang, *Proc. Combustion Institute*, **34**, 2565 (2013).
11. F. Tang, L. Hu H, L.Z. Yang, *Int. J. Heat Mass Transfer*, **75**, 130 (2014).