Study on Feasibility of Automatic Sprinkler System Applied in Underground Tunnel

DENG Yan-li*, MI Xiao, ZHU Shu-min

School of Environment and Civil Engineering, North China Institute of Water Conservancy and Hydroelectric Power, Zhengzhou 450008, Henan, China

Abstract

For realizing the characteristics of underground fire and the actuality of fire protection facilities, and putting forwards the advice, we should set automatic sprinkler systems in underground tunnels. In this paper, the smoke development and the temperature distribution was simulated using field model (FDS). And the comparisons between the two cases were made. From the results we can see that setting automatic sprinkler systems in underground tunnels has both advantages and disadvantages. But considering synthetically it is feasible.

Keywords: underground tunnel fire; FDS; automatic sprinkler systems; feasibility

1. Introduction

Nowadays, traffic is the major rub that most of cities met with in spreading. And developing public traffic is the main means for solving the problem. According to developed countries’ experience, underground is the essential measure to solve the problem of public traffic in cities. At present, several big cities such as Beijing, Shanghai, Tianjin, Guangzhou and so on have constructed underground and plunged into running. In subsequent ten years, more than ten cities will construct underground and more than twenty ones will intend to in China.

Because the great mass of underground is deeply belowground, enwrapped by rock and soil, there is fewer channels connecting with outside and channels is confined. At the same time, the underground tunnel with crowd of occupants has small room, so the heat accumulation in the tunnel is very serious and temperature arises sharply in case of fire. As a result, the fire will spread and cause serious economy loss and casualty of human beings. On the other hand, many undergrounds are fortress of public traffic, so great damage to tunnel structure caused by fire can interrupt the whole city’s traffic and stop underground running for a long time and the indirect loss may be immense. So studying on the happening and developing rule of tunnel fire to reinforce the fire safety design is of great importance.

According to Chinese code of design for underground fire safety, in the tunnel hydrant and chemistry fire extinguisher are the main fire safety facilities at present. Then between the alarm ringing and the firemen arriving at the spot there is some delay time. Because of the peculiar characteristic of underground tunnel fire, in the delay time the fire will spread so wide and smoke will permeate the whole tunnel that firemen cannot make sure where is the fire origin, saying nothing of entering the tunnel to put out fire with the hydrant of tunnel. So in most fire cases the inside hydrant is useless. Over here we advise adopt sprinkler systems, the most advantage is that sprinkler systems can automatically act to extinguish the early fire. However, because of the conception confinement there are fewer underground tunnels in which fire safety designer set sprinkler systems, only in some Japanese tunnels.

The argument reasons of whether setting sprinkler systems in underground tunnels are various. Discommenders deem that: (1) Expense is high; (2) Spray will disorder top smoke and adulterate the clean air with the high temperature smoke, and this goes against evacuation; (3) Droplet will density high temperature water vapor and make visibility descent. Assentients deem that: (1) Sprinkler systems can put out the early fire and possess the alarm function; (2) Spray can reduce the whole area temperature and dilute the density of smoke; (3) The system security is high and work timely to extinguish...
fire; (4) Setting sprinkler systems is not expensive relative to the whole project investment. In one word, the argument focuses on the expenses and the security.

Firstly, we study the reason why expenses boost and the scale of every factor in underground construction with sprinkler systems in Japan: (1) The expenses account for 55% due to the increased depth; (2) The expenses account for 18% due to the diversification of the station establishment and the platform lengthening; (3) The expenses account for 15% due to the service quality advancement, the work capability enrichment and study expense of safety and energy saving; (4) The expenses account for 14% due to the confiscation land difficulties; (5) The expenses account for 10% due to circuitry crossover management and deterioration of construct condition; (6) The expenses account for 9% due to environment, tragedy prevention and safety countermeasure; (7) The expenses account for 1% due to dealing with the running of straight arrival engine. From above we are conscious of that the expenses account for only 9% due to environment, tragedy prevention and safety countermeasure, therefore the fire protection expenses account for only a little part of the total expenses. On the other hand, fire protection is vital thereby setting sprinkler systems will not increase evidently the total expenses. Secondly, the argument focus is whether setting sprinkler systems in underground tunnel is favorable for evacuation and fire extinguishment. Here we adopt the application software FDS programmed by NIST to simulate a supposed underground tunnel fire. From the results we analyse the rule of smoke and temperature development, the volume fraction of CO and soot in two cases to testify the advantage and disadvantage of setting sprinkler systems.

2. Brief introduction of FDS

Fire Dynamics Simulator (FDS) is a field simulation model programmed by NIST, with a 25-year history. The first version was published in February 2000, and soon it became familiar. FDS Version 2 was publicly released in December 2001 and version 3 in November 2002. Recently version 4 was publicly released in August 2004 and the one is in common use right now. FDS can solve numerically a form of the Navier-Stokes equations appropriate for low-speed, thermally-driven flow with an emphasis on smoke and heat transport from fire. The model utilizes mass conservation equation, momentum conservation equation and energy conservation equation, with rectangular meshes compartmentalizing the computational domain, to solve numerically the equations in every mesh. The model consists of two parts. The first is FDS, the main program solving differential equations; the second is SMOKEVIEW, a visualization program to display the results of an FDS simulation. It is possible to perform Large Eddy Simulation (LES) or Direct Numerical Simulation (DNS). Our simulation mode of operation is LES.

3. Model of tunnel

This paper chooses part of the single-hole-double-line underground tunnel as the simulation object. And simulation performs LES. Because LES requires a relatively fast CPU, but our computer hardware is confined, we suppose the tunnel as the 80m long rectangle tunnel, which width is 8m and the height 6m. The top and the metope are built by non-flammable concrete which fire-tolerance time is not less than 2 hours.

When a fire happened in tunnel, the longer the distance is between the fire origin and the exit, the more difficult it is for firemen to rush to save life and property. So it is most dangerous for evacuation that fire break out in the middle of tunnel. For the sake of more simple simulation, the paper supposed everything is non-flammable except the fire origin (x=40.0m). We divide the tunnel into three sections. In the middle section the meshes are fine, with the 0.1\times0.1\times0.1 m square. In both sides sections the meshes are coarse because of the confinement (FIGURE 1). The material of fire resource is kerosene. As oil burns fast and can reach fixed value. Here we select the Heat Released Rate Per Unit Area (HRRPUA) is 10MW/m², and the area is 1m\times1m.

This paper simulate two cases that setting sprinkler systems in tunnel or not. The K-factor of sprinklers is K=79. And the sprayers are distributed in square, with span 3.6m between each other. During the calculation, the temperature at 1m from fire origin, at 2m, at 3m, at 13m, at 23m is recorded; the volume fractions of soot and CO are also used to monitor the temperature field growing and the height of smoke layer development.

FIGURE 1: Tunnel section and the distribution of sprayers
4. Results of simulation

Figure 2 is the temperature growing every time step in tunnel vertical section, different shade of color denoting temperature. From the pictures simulating at 106s, 330s, 500s we can make out that smoke develops symmetrically due to the fire origin is in the middle of tunnel. From below figures, sprinkler systems can significantly reduce average temperature in the whole tunnel room. Most of all, spray can reduce the top temperature and this is of great advantage to protect tunnel structure.

Fire grows at 106s:
Not setting sprinkler systems:

 Setting sprinkler systems:

Fire grows at 330s:
Not setting sprinkler systems:

 Setting sprinkler systems:

Fire grows at 500s:
Not setting sprinkler systems:

 Setting sprinkler systems:

FIGURE 2: Temperature in vertical section growing comparison in two cases.

Figure 3 is comparison of the height of smoke layer and the mixture in vertical section in two cases at different time step. From the result, when fire grows at 14s, the sprinkler at fire origin begins to act to spray. From below figures when fire grows at 30s there is little turbulence and it will not obstruct evacuation right now. And when fire grows at 120s, the top smoke layer is disarranged badly and air in tunnel begins to become mixture between the top polluted smoke and the below clean air. As a result, visibility comes down, so it is dangerous for those who have not run out of 80m area in 120s. However, the speed of evacuation is generally 1.3m/s according to the empirical data, so people will run through 80m in just 60s. In one word, setting sprinkler systems will not affect evacuation.

Fire grows at 30s:
Not setting sprinkler systems:

![Image](image1)

Setting sprinkler systems:

![Image](image2)

Fire grows at 120s:

Not setting sprinkler systems:

![Image](image3)

Setting sprinkler systems:

![Image](image4)

Fire grows at 300s:

Not setting sprinkler systems:

![Image](image5)

Setting sprinkler systems:

![Image](image6)

FIGURE 3: Density variety in vertical sections in two cases.

Figure 4 is temperature compare at the height of 2.0m in two cases. From the figures we can see that sprinkler systems can reduce the fire origin temperature. For (40.0,4.0,2.0), without sprinkler systems temperature rises up to 800°C, and it is of great damage for the concrete tunnel structure. Because when temperature is higher than 600°C, the compressive strength of concrete will descend accelerated as the temperature rises. After setting sprinkler systems temperature goes down to about 200°C. And the temperature field less than 400°C is ‘low temperature function of concrete structure’, so it will not change the carrying capacity. Therefore setting sprinkler systems has advantage for protecting tunnel inner structure and is advantageous for renewal and resuming traffic after fire[3]. From below figure, temperature in the area far from fire origin will rise, but relative to ambient temperature 20°C, the temperature only rises to 30~40°C at the point far away from fire origin, and this will not harmful to health. In one word, setting sprinkler systems has advantage for protecting tunnel inner structure and will not badly baffle evacuation.
Figure 5 is soot volume fraction compare at the height of 2.0m in two cases. From the figures we can see that soot volume fraction increases due to the inadequate combustion of fuel. The reason of inadequate combustion is that the droplets suffocate and cool fuel if setting sprinkler systems. But the soot volume fraction increases only a little. The soot volume fraction reaches 0.5ppm at the point 1m away from fire origin and only 0.005ppm at 3m away from fire origin.
Figure 6 is CO volume fraction compare at the height of 2.0m in two cases. From the below figure we get that when sprinkler systems are set in tunnel, the fuel will be inadequately combusting and the CO density increases. It is disadvantageous for evacuation because of the CO density increasing. However, from the result we can see that CO volume fraction reaches about 700ppm at the point 1m away from fire origin, about 20ppm at 2m away, only 1ppm at 3m away. As a result, compared with not setting sprinkler systems in the case, CO density increases a little with setting sprinkler systems, especially for the area out 3m away from fire origin. It doesn't hamper evacuation. So sprinkler systems just influence the smoke density in the area surrounding the fire origin, but in this area the temperature influence is more harmful than smoke function.
Figure 7 is temperature compare at different heights in vertical section in two cases. From the first and second picture we can conclude that sprinkler systems can significantly reduce the fire origin area temperature. The droplets absorb large amount of heat so that it can change into vapor. From the other pictures with sprinkler systems we can see that elsewhere temperature rises in a way, the reason is that the droplets disturb the flame nearby the fire resource. So we can say heat is ‘averaged to be distributed’ in the whole tunnel. And there is delay time in the process of ‘averaging’. We can also see from the below figure that the delay time is about 150s, and in 150s all the people in tunnel must all have evacuated into safe locations. In conclusion, in tunnel without sprinkler systems all heat accumulates at the top and temperature rises severely to 800°C, it can damage the top concrete structure. On the other hand, setting sprinkler systems in tunnel the droplets can absorb a large amount of heat. Additionally, all heat is ‘averaged’ in the whole domain because of spray disturbance. The heat and temperature ‘averaging’ function has great advantage for protection tunnel structure.
FIGURE 7: Temperature comparison at different height in two cases.
5. Conclusion

This paper applies field model code (FDS) to simulate the smoke development and the temperature growing in the case of fire in tunnels with sprinkler systems or not. The simulation results show that setting sprinkler systems in underground tunnels has both advantages and disadvantages. Employment of sprinkler system can make the top high temperature fall to equilibrium to safeguard tunnel structure and it is helpful for tunnel renewal and traffic resuming after fire incident. But because of droplets fuel combusts inadequately, the volume fractions of soot and CO rise. It may hinder occupant to evacuate under the fire. But as long as timely safe evacuation of people is organized, the harmful smoke, such as CO will not interfere evacuation. Synthesizing above, setting sprinkler systems in underground tunnel is feasible.

References