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Research Article

Effect Analysis of Fans Activating Time on Smoke Control Mode for Road Tunnel Fire

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Abstract: With the development of economy, more and more road tunnels have been built. Due to the relatively isolated environment of the tunnel, fire protection is the most important factor for the safe management of tunnel operation. During the fire process, many people are killed by the fire smoke. As for preventive measures of road tunnel fire, smoke exhaust system is the most effective way to control the spread of fire smoke. Based on full size tunnel fire test and simulation analysis, this study carries out effect analysis of fans activating time on smoke control mode for road tunnel fire. The corresponding results are useful to establish fire control strategy and personnel evacuation plan for tunnel management system.

Keywords: FDS, full size tunnel fire test, numerical simulation, opening time, road tunnel fire

INTRODUCTION

Recent incidents however have drawn widespread attention to the risks of fires in road tunnels (e.g., Channel Tunnel, Mont Blanc, Tauern, Gotthard). The incidents have resulted in casualties as well as large direct and indirect economic damage. The control of smoke flow during a road tunnel fire is often an important part of fire safety measure. On the other hand, CFD (Computational Fluid Dynamics) simulations are increasingly used to estimate the effects of fires in road tunnels. Hitoshi *et al*. (2003) have a research of the fire properties in near field of square fire source with longitude ventilation in tunnels; (Wu and Bakar, 2000) study the control of smoke flow in tunnel fires using longitudinal ventilation systems-a study of the critical velocity; (Yuko, 2003) study the heat release rate of gas online pool fire in large cross sectional tunnel; (Anders and Haukur, 2005) have a research of the gas temperatures in heavy goods vehicle fires; (Anders and Haukur, 2005) study the numerical simulation of the caldecott tunnel fire, april 1982. nistir7231; (Ballesteros-Tajadura, 2006) analyze the influence of the slope in the ventilation semi-transversal system of an urban tunnel. However, little work has been done to analyze the relationship between fans activating time and smoke control method. Based on full size tunnel fire test and with the help of FDS simulation software, this study carries out effect analysis of fans activating time on smoke control mode for road tunnel fire. The full size tunnel fire test as well as simulation results of smoke distribution feature are discussed. The corresponding results are useful to establish fire control strategy and personnel evacuation plan for tunnel management system.

FULL SIZE ROAD TUNNEL FIRE TEST

In The size of the test tunnel is constructed by 1:1 proportion to a certain practical road tunnel. The tunnel is composed by the main road tunnel part and ventilation duct, which is about 100 m long, 12.7 m wide and 6.7 m high, as shown in Fig. 1. The test tunnel is a steel reinforced concrete structure. There is smoke exhaust duct at the top of the tunnel, whose cut area is about 11 m^2. There are two smoke outlets at the bottom of the exhaust duct, whose spacing is 60 m. As for fire test purpose, the area of the smoke outlet is changeable.

There are four fire test scenarios with two fire scales of 10 MW and 25 MW 0# diesel pool fire. During the fire test, there are two sizes of smoke outlet. One is 4 m×1.25 m on both sides of the fire source, the other is 6 m×2 m on one side and 4 m×2 m on the other side of the fire source. Before the beginning of the test, the longitudinal tunnel ventilation velocity is adjusted to 1.3 m/s, then the exhaust fan is activated and the amount of exhausting air is 130 m^3/s. After that, the fire source is ignited and the time of the fire test is counted. The change of temperature distribution can be measured by thermocouple. The visibility and the height of smoke layer can be identified by height ruler. The change process of the ventilation system from normal mode to smoke exhaust mode is not considered. Figure 2 shows

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Fig. 1: Exterior and interior view of the test tunnel

Fig. 2: Smoke exhaust test in 25MW 0# diesel pool fire, with size of smoke outlet as 4m×1.25 m

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The fire test indicates while the fire smoke arrive the smoke outlet, first it always tends to bypass the outlet and then it is exhausted by the fans. As for long type outlet, increasing the lateral length of the smoke outlet which is parallel to the tunnel would reduce flowing around smoke and improve smoke exhausting efficiency. Figure 3 shows the smoke exhaust test in 25MW 0 # diesel pool fire, with size of smoke outlet as 6 m×2 m and 4 m×2 m.

Fig. 3: Smoke exhaust test in 25MW 0# diesel pool fire, with size of smoke outlet as 6 m×2 m and 4 m×2 m

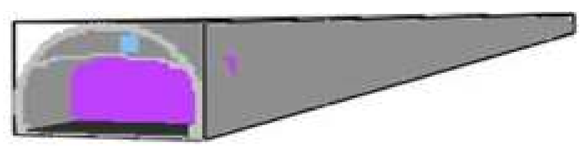

Fig. 4: FDS model of road tunnel

SIMULATION MODEL AND SCENARIO

FDS model of road tunnel: In accordance with the full size road tunnel fire test results and with the help of FDS software, a simulation model of the road tunnel is constructed. The length of the FDS model is 500m. All boundary conditions are corresponded with the fire test situation. Figure 4 gives the FDS model of road tunnel.

Simulation scenario: In the normal operation of the tunnel, the longitudinal ventilation mode is adopted. Once the fire takes place, it changes to be a concentrated smoke exhaust mode. Through the simulation research, the transformation of the tunnel ventilation mode will change the tunnel air flow environment, which affects the spread of air. In the process of transformation of the tunnel ventilation type, there are three important time points:

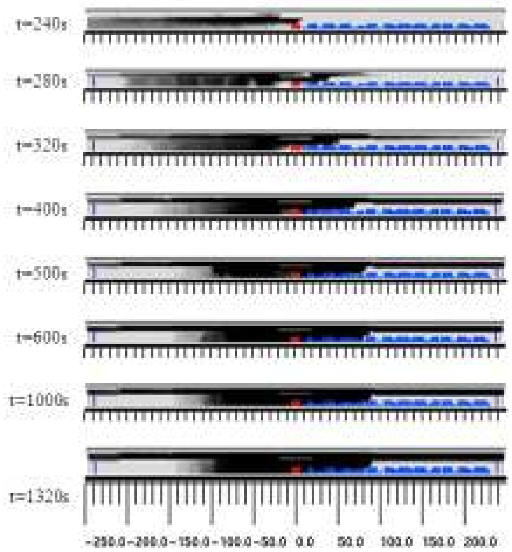

Fig. 5: Smoke spread process in scenario 2

Table 1: Simulation scenario

Scenario	Longitudinal fan closing time (s)	Smoke outlet opening time (s)	Fans activating time (s)
1	165	180	210
2	165	210	240
3	165	240	270
4	165	270	300
5	165	300	330
6	165	330	360
7	165	360	390
8	165	390	420
9	165	420	450

Vehicle driving direction is the downstream side, while the other side is upstream

longitudinal fans closing time, smoke outlet opening time and exhaust fans activating time. This study mainly focuses on the effect of fans activating time to the influence of smoke control. According to the actual situation of the tunnel operation and considering certain time interval, the simulation scenarios are set as shown in Table 1. Figure 5 shows the smoke spread process in Scenario 2.

ANALYSIS OF SIMULATION RESULTS FOR SMOKE SPREAD

The simulation time is 165s and the normal ventilation fans are closed. The airflow continues to flow in longitudinal direction of the road tunnel and forces the smoke flow to downstream because of inertia. At 240s or so, fire smoke begin to produce countercurrent and spread to the upstream. Before the fans be activated, smoke spread at the upper space of the tunnel and is layered. When fans are started, flow field changes and smoke sinks in disorder. After the airflow is stable, smoke within the downstream area of the tunnel begins to flow to the fire source under the effect of the ventilation wind on both sides. The fans activating time has an important effect on the disordered sinking of the smoke. If the fans are activated earlier, because fire is on a smaller scale and less smoke is produced, when fans be started, most of the smoke would be exhausted by smoke outlet, part of smoke would be brought into lower space of the tunnel by disordered air. However, due to little amount of smoke, the visibility could be still maintained to a certain level. Then with the expansion of the fire scale, the visibility decreases gradually. As for the delay of fans activating time, smoke in the tunnel become more and more thick, when the fans are activated, most of the smoke gathered near the smoke outlet and could not be exhausted immediately and would sink due to the airflow in disorder, causing the visibility in the lower space of the tunnel be reduced quickly.

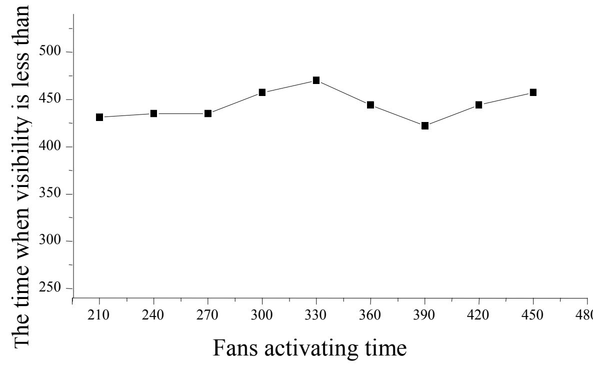

Fig. 6: Relationship curves between the fans activating time and the time when the visibility in the upstream of the fire source is less than 5 m

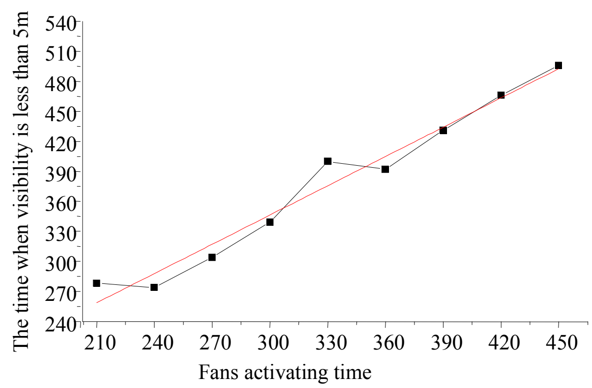

Fig. 7: Relationship curves between the fans activating time and the time when the visibility in the downstream of the fire source is less than 5 m

The relationship curves between the fans activating time and the time when the visibility in the upstream or downstream of the fire source is less than 5m are shown in Fig. 6 and 7.

As shown in Fig. 6, the time when the visibility is less than 5 m in the upstream of the fire source in each scenario is about 450s or so, concluding that the fans activating time has little impact on fire smoke spread.

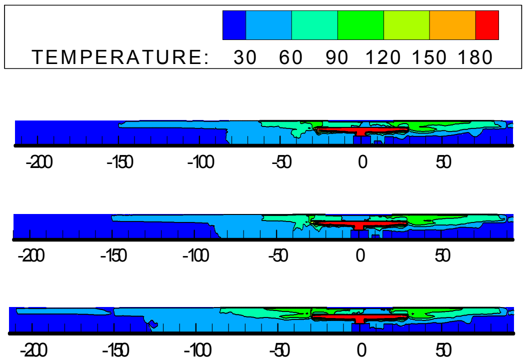

Fig. 8: Temperature distribution at 420s

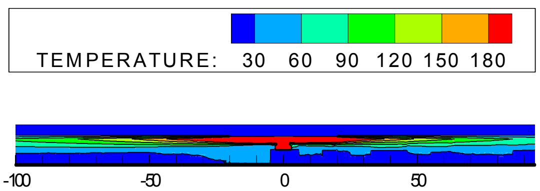

Fig. 9: Temperature distribution at 420s in scenario 9

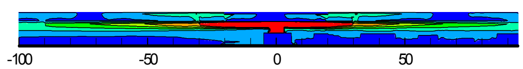

Fig. 10: Temperature distribution at 450s in scenario 9

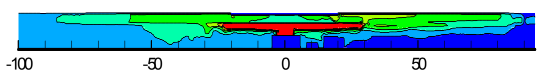

Fig. 11: Temperature distribution at 600s in scenario 9

As shown in Fig. 7, overall, the delay of fans activating time would delay the time when smoke sink in the downstream of the fire source. The entire curves present linear relationship. By linear curve fitting method, the following equation (1) could be achieved:

$$t_{vis} = 53.81+0.975\times t_E \quad (1)$$

where,

t_{vis} = The time when the visibility is less than 5m in the downstream of the fire source

t_E = Fans activating time, between 240s to 480s.

ANALYSIS OF SIMULATION RESULTS FOR TEMPERATURE FIELD

As shown in Fig. 8, at 420s in scenario 2 to 4, fans have already been activated. The area where the temperature is larger than 180°C is controlled between two smoke outlets, i.e., from -30 m to 30 m.

As shown in Fig. 9 to 11, after the fans be activated, the scale of the smoke spread gradually decrease.

CONCLUSION

Based on full size tunnel fire test and with the help of FDS simulation software, this study carries out effect analysis of fans activating time on smoke control mode for road tunnel fire. As for fans activating time, nine simulation scenarios are set. Through the comparison and analysis of the simulation results, we could conclude as follows:

- Once the longitudinal ventilation fans are shut down, most of the smoke continues to spread downstream due to the force of inertia. Within a certain length of downstream of the fire source, smoke spreads in the upper space of the tunnel and be layered quite well. Smoke produces countercurrent at 240s or so and begins to spread upstream
- After the fans are activated, smoke spread would be disturbed in the downstream of the fire source and the smoke would sink. The time when smoke sinks and fans be activated has an approximate linear relationship. Through the linear curve fitting method, we could obtain the formula which indicates the relationship between the time when the visibility is less than 5m in the downstream and the fans activating time. Fans activating time has little impact on smoke spread in the upstream
- After the fans are activated, the area where the temperature is larger than 180°C is controlled between two smoke outlets which are on both sides of the fire source. Fans activating time has a certain effect on the temperature distribution in the road tunnel. The earlier the fans are started, the easier the heat is exhausted

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