The impact of jet fans layout on the CO concentration distribution inside tunnel for the congestion scenario

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Abstract: Air pollution inside tunnel has attracting more people's attention in China. The occurrence of traffic accident in the rush hours would cause widespread traffic congestion inside tunnel. This may further lead to accumulation of air pollutants near the accident location. To analyze the accumulative effect, the air velocity and CO concentration under different jet fans layout are predicted by use of the multi-segments model. The results show that the occurrence of the accident does influence the spatial-temporal distributions of air velocity and CO concentration. After the accident, air velocity in the congestion region drops significantly and CO concentration jumps downstream the accident location. For a traffic accident-induced congestion scenario, increasing the jet fans in the upstream area is more effective to dilute the air pollutants inside tunnel.

1. Introduction

As one of the modes of transportation, urban road tunnel has been widely used in the construction of cities to relieve the traffic pressure. The occurrence of vehicle traffic accident easily triggers the massive traffic jam in tunnel especially in rush hours. The former researches focus on the thermal environment inside tunnel [1-2], air pollution [2-3], tunnel traffic management [4-5], etc. Researchers have conducted a series of field measurements and found that the air pollution inside tunnel was serious. Due to the limited measuring points, it is impossible to get the detailed air pollutant distribution inside tunnel for a congestion scenario. To solve the problem, the CO concentration before and after the accident is predicted by use of multi-segments model proposed in the former research [6]. The effect of jet fans' layout on CO dilution inside tunnel is analyzed. The results can be used as the supported data for tunnel management.

2. Traffic flow characteristics for the congestion scenario

The Yuhan Road Tunnel is a two-way four-lane road tunnel. It is about 2.79 km long with a cross-section of about 32.8 m^2. There are 10 sets of jet fans in the southbound tunnel, each set has 2 jet fans. Detailed on-site measurements were conducted in the southbound direction during the evening rush hour on January 9, 2020. And only half of the jet fans were operated during the tests, N1=5, N2=5, as exhibited in Fig.1. Four measuring points (a-d#) are placed along the tunnel to monitor the air velocity and CO concentration. At 18:36, a car broke down at 2000 m from the tunnel entrance, which completely blocked one lane of the tunnel. The combination of the traffic accident and the peak traffic flow caused the widespread congestion in the tunnel. As a consequence, the vehicle speed in the region upstream the accident location decreased rapidly to lower than 10km/h, and the number of vehicles in this region is about 3-5 times higher in comparison with the pre-accident value, as shown in Fig.2.

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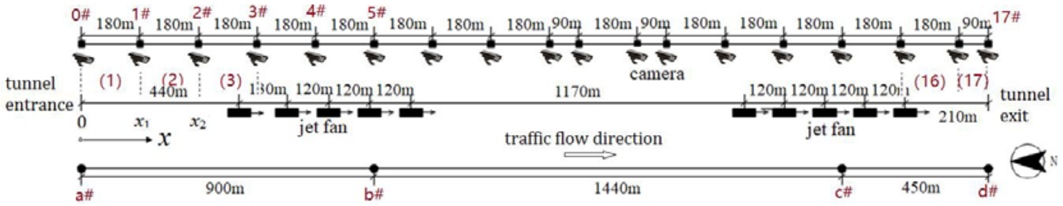
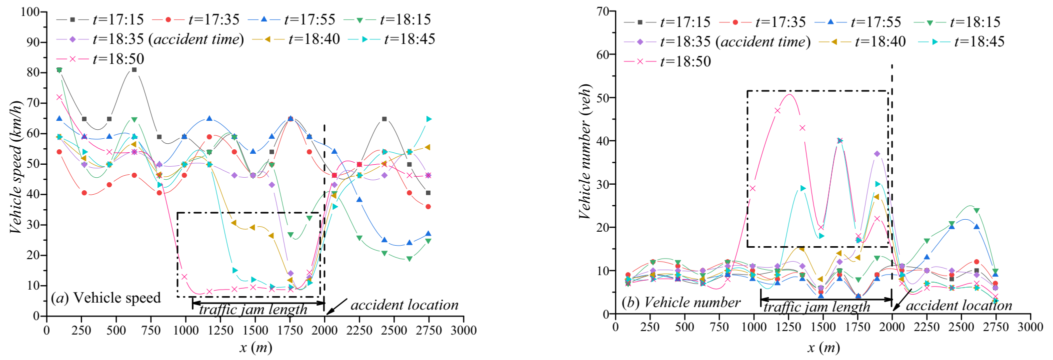


Fig.1 Longitudinal measuring points, camera and jet fan layouts



(a) Vehicle speed (b) Vehicle number

Fig.2 Spatiotemporal characteristics of vehicle speed and vehicle number before and after the accident [6]

3.Results discussion

3.1 Actual distribution of CO concentration

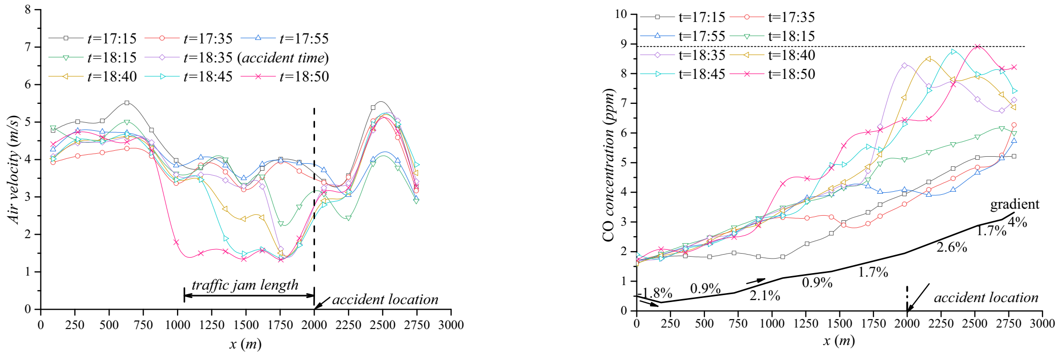
The spatial-temporal distribution of air velocity and CO concentration are predicted by use of the multi-segments model (N=17). The computing segments and computing nodes are shown in Fig.1. For each segment, the governing equations of air velocity (u_I) and pollutant concentration (C_i) are listed as below [7]:

$$\begin{cases} F_1 + F_2 + F_3 + F_4 = \rho_i A_t \Delta x_i \dfrac{du_I}{dt} \\ \rho_i u_I A_t \dfrac{dC_i}{dt} = S_I \end{cases} \quad (1)$$

Where F_1 is the piston force of moving vehicles, N; F_2 and F_3 is the friction force and the the pressure difference between two portals, N; F_4 is the pressure rise imposed by jet fans, N. S_I is the emission rate of pollutant in *I-th* segment. The key data used in the theoretical model, including resistance coefficients, drag coefficient of vehicles and the proportion of vehicle emission standards can be found in the reference [6-9]. The on-site measurement results of the traffic flow, air velocity and CO concentration are used as the boundary conditions [10].

As shown in Fig.3, the minimum air velocity inside tunnel is larger than 3m/s before the accident, which means that 10 jet fans (N1=5, N2=5) can meet the ventilation requirements in the evening rush hours. The CO concentration increases gradually along the tunnel length, its increase gradient ($\Delta C/\Delta x$) is about 1.6-2.3 ppm/km. After the accident, the traffic congestion quickly propagates upstream the accident location with time goes on. The air velocity in the congestion zone decreases significantly to 1.3-1.4m/s. As a result, the CO concentration near the accident location shows a high jump (as much as 5ppm). And its gradient ($\Delta C/\Delta x$) increases rapidly to 7.9-14.5 ppm/km, which is about 3.4-9 times of the pre-accident value.

 https://doi.org/10.1051/e3sconf/202235602048



(a) Air velocity (b) CO concentration

Fig.3 Predicted distribution of air velocity and CO concentration [6]

note: only half of the jet fans are opened before and after the accident (N1=5,N2=5) in the actual situation

3.2 Jet fans' layout on the distribution of CO concentration

According to the theoretical model, jet fans layout may affect the air velocity, and further influence the diffusion of air pollutant inside tunnel. Therefore, different combinations of jet fans in the first and latter half of the tunnel after the accident are taken into consideration in the following analysis. The fans layout for different cases is specified in Table 1.

In the region downstream the accident location, increasing 5 jet fans in the first or latter half of tunnel after the accident, would obviously alleviate the CO accumulation. As exhibited in Fig.4, the peak CO concentration decreases from 9 ppm (actual situation) to 7 ppm (case 1, case 2). As time goes on, the peak CO concentration continues to move towards the tunnel exit. And the maximum value shows a slight increase. However, the reverse is true for CO concentration upstream the accident location. The CO could not be diluted effectively by only opening more fans in the latter half of the tunnel. The environmental situation for case 1 is superior to that of case 2. For case 3, all the jet fans inside the tunnel are turned on after the accident, the CO concentration both in the upstream and downstream area continues to decrease in comparison with other cases. The CO concentration drop downstream the accident location is about 0.25 ppm.Overall, it is more effective to dilute the air pollutants by increasing the jet fans in the upstream area for a traffic accident-induced congestion scenario.

Table 1 Jet fans layout for different cases

Jet fans layout	Case 1		Case 2		Case 3	
	t<18:35	t≥18:35	t<18:35	t≥18:35	t<18:35	t≥18:35
Jet fans in the first half tunnel N1	5	10	5	5	5	10
Jet fans in the latter half tunnel N2	5	5	5	10	5	10

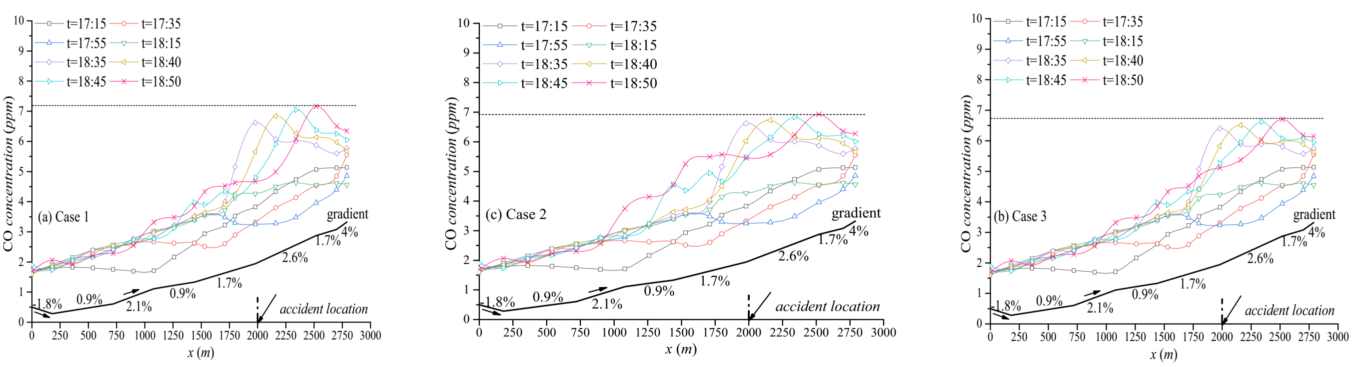


Fig. 4 Predicted distribution of CO concentration for different jet fans layout

4.Conclusions

The occurrence of traffic accident in the rush hours would lead to significant distribution variations of vehicle speed and vehicle number along the tunnel length. By use of the multi-segments model, the CO concentrations under different jet fans layouts are predicted. The following conclusions can be drawn: (1) Under the circumstance of the same jet fans layout, the air velocity in the congestion zone decreases significantly to 1.3-1.4 m/s after the accident. The CO concentration gradient near the accident location increases rapidly to 7.9-14.5 ppm/km. (2) Increasing 5 jet fans in the first or latter half of tunnel would help to dilute CO downstream the accident location. The peak CO concentrations drop by 2 ppm. Opening all the jet fans inside tunnel only leads to the maximum CO concentration further drop by 0.25 ppm. (3) The augments of jet fans in the latter half of tunnel does not help for CO dilution in the upstream area.

5.Acknowledgement

The work was supported by the Natural Science Foundation of Shandong Province of China (ZR2021ME200) and National Natural Science Foundation of China (51108254).

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