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Study on the fire spread and evacuation of subway tunnel

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Abstract. It is difficult to evacuation when the subway tunnel fires owing to the characteristics such as narrow space, less exits and larger personnel flow density. So it is very important to determine the safe evacuation route according to the fire spreading characteristics. In this paper, taking one subway tunnel as an example, the simulated models including natural draft and mechanical draft are built, the temperature, visibility and the people distribution in tunnel, at exit and entrance when the fire happened are all be simulated, and the required safety egress time (RSET) and available safety egress time (ASET) are simulated and calculated, too. The calculated results show that the evacuees can safely leave the fire-tunnel within 170s if natural draft is used, and they are safe if they can leave the fire-tunnel within 284s when mechanical draft is used.

Key words. Subway tunnel, fire spread, evacuation.

1. Introduction

With the development of urbanization in China, the problem of traffic jam becomes more obvious, and one of the methods to solve this problem is to build subway. By the end of 2016 the overall length of urban rail transit lines reach 4152.8km in mainland China, of which the subway lines reach 3168.7km, accounting for 76.3%. On current projections, more than 30 big cities will have their own urban rail transit in 2020, and the length will exceed 9000km. On one hand, the subway brings the convenient traffic environment, on the other hand, it arouses a large number of accidents which lead to serious casualties and a great loss of property[1,2]. However, the statistical results showed that the fire accidents occupy 65% of the subway accidents[3]. So, it is very important to study the occurrence mechanism and draw up

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a detailed list of measures to control fire accident to decrease subway accidents and casualties. In recent years, many scholars at both home and abroad have studied the fire accident. Yasushi O. and Graham T. A. studied smoke movement in the horizontal tunnel using model experiment[1], S. Simcox et al. simulated the fire spread in the subway platform[2], S. Bari and J. Naser studied the densities of O_2 , CO_2 and CO in Domain tunnel using FLUENT6.0[3], B. Yu et al. developed evacuation model of subway fire[4].

In this paper, taking one subway tunnel as an example, the temperature and visibility of natural draft and mechanical draft are be simulated, and the required safety egress time (RSET) and available safety egress time(ASET) are all simulated and calculated, too.

2. Basic Theory

People can be evacuated whether or not when subway tunnel fired, it mainly decided by the relationship between the required safety egress time (RSET) and available safety egress time (ASET). People can be evacuated safely if is RSET lager more than ASET, on the contrary, people can not leave the fired tunnel safely.

The RSET includes the alarm time, response time and evacuation time in general, and it can be expressed as follows[5−7]:

$$RSET = t_{perc} + t_{resp} + t_{move} \tag{1}$$

Where $t_{perc}$is alarm time,$t_{resp}$is response time and$t_{move}$is evacuation time.

In the Equ.(1), thet_{perc}andt_{resp}can be determined according to the fire place and personnel condition. Kikuji Togawa established set of simple equation oft_{move}[8], and it can be expressed as follows:

$$t_{move} = \frac{Q}{NB} + \frac{L}{V} \tag{2}$$

Where Q is the numbers of evacuation, N is people numbers through door, B is door width, L is the distance between door and the end of evacuation queue, and V is the crowd walking speed.

Dongkon Lee et al consider that the personnel flow and walking speed are related to the channel type and personnel density. The relationship between the crowd walking speed and population density are shown in Table1[6−8].

Table 1. The crowd walking speed & population density

Channel type	Flow conditions	Personnel density pepole/m2	Walking speed m/s	people numbers passing through door /(m/s)
Stair(upward)	low	<1.9	0.8	0.43
	high quality	1.9-2.7	0.4	0.75
	middle	2.7-3.2	0.22	0.62
	crowd	>3.2	0.1	0.32
Channel andcorridor	low	<1.9	1.4	0.76
	high quality	1.9-2.7	0.7	1.3
	middle	2.7-3.2	0.39	1.1
	crowd	>3.2	0.18	0.55

3. Fire Simulation

3.1. Simulation Models

At present, two kinds of models including steady state and non-steady state are used to describe the fire development. The steady-state model treats the rate of heat release throughout the fire as a constant value, and that is ideal for the entire fire process[7,8]. Steady-state fire models often determine the design parameters based on the maximum rate of heat release that may occur in the building, which represents the worst possible fire situation in the building, and the results are conservative.

The actual combustion process is a development process consisting of the initial slowly growing period and the subsequent significant growth period. The t2-fire model is usually used to describe the process of the heat release rate over time during a fire[1-3]. It can be described as:

$$Q = at^2 \tag{3}$$

where Q is the heat release rate (kW), in this study, it equal to 5MW[5-11], α is the fire growth coefficient (kw / s^2) which equal to 0.04689 kw / s^2 in this study and t is the fire development time (s).

In fire risk assessment, the setting of the fire source is mainly based on the determination of the fire development curve which usually consists of two main parameters including fire growth type and the maximum heat release rate. The materials used in subway vehicles generally meet the requirements of flame retardancy, low smoke and low toxicity, but the cables, vehicle connection lanes and passenger's luggage will still be subject to fire and emit toxic gases. In this study, the metro vehicle consists of 6 cars train, and the width is 2.8m, the height is 3.9m, and the total length is 120m. The train is equipped with 8 sets of doors per carriage, the door width is 1.3m and height is 1.85m. The maximum numbers of train are 1814. Two states including natural draft and mechanical draft[6-8](air speed=3.0m/s) are simulated.

The simulation model is 300m × 4.8m× 7.0m, and the following safety criterions are set, (1) The visibility of 1.7 meters high is no less than 5m, (2) The temperature of 1.7 meters high is not more than 600^oC, (3) The CO concentration of 1.7 meters high a not more than 250ppm. The simulation model is shown in Fig.1.

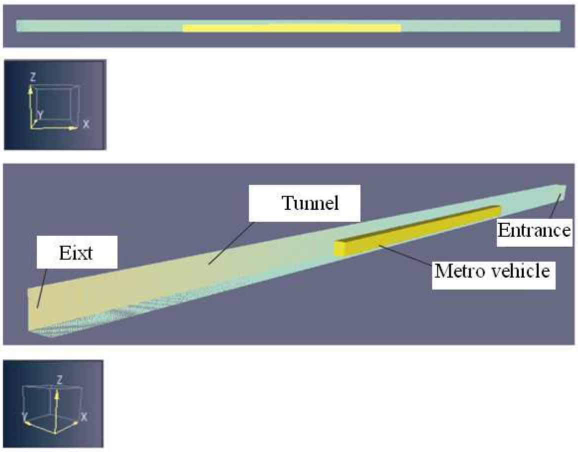


Fig. 1. Simulation model

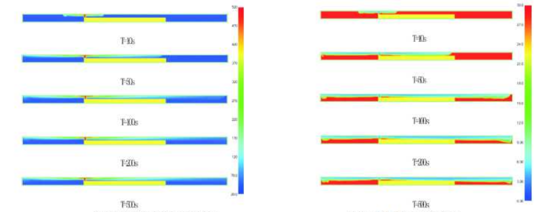
3.2. Simulation Results and Analysis

3.2.1Natural draft

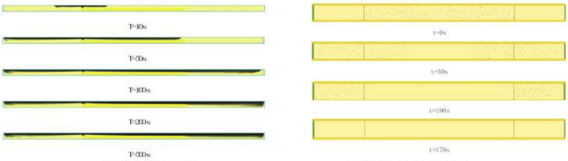
The simulated results of temperature and visibility variation and smoke diffusion of the subway tunnel with natural draft are shown as Fig.2(a), (b) and (c). From the figures we can know that when the fire broke out, the smoke and temperature spread from ignition source to both ends of the tunnel, and visibility decrease quickly. When t=50s, smoke spread to the exit and entrance, and the spreading speed is about 1.8m/s. When t=100s, smoke and temperature spread to bottom, and when t=200s, the subway tunnel is filled with high density gas which will spread to the station, at that time, the temperature of bottom is about 1200C, and the visibility is about 5m.

When the fire happened, the evacuees will get off the train and then leave the tunnel from a certain path. The simulated result of evacuation process is shown as Fig.2 (d), and the people distribution in tunnel or at exit and entrance are respectively shown as Fig.2 (e) and (f). From the Fig.2 (d), (e) and (f) we can know that when t=0s, all people are around the train, and then move to exit or entrance, when t=170s, the all evacuees have leaved the fire tunnel.

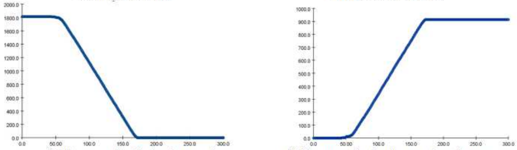
When the fire happened in subway tunnel, people can be safely evacuated whether or not which will be determined by the relationship between RSET and the ASET. In this paper, the RSET is determined according to the fire indexes within the scope of 1.7m. The temperature and visibility in the tunnel when t=600s are respectively shown as Fig.3 and Fig.4. The simulated results show that it is safe if the evacuees leave the fire tunnel in 600s.



(a) Temperature variation (b) Visibility variation



(c) Smoke diffusion (d) Evacuation process



(e) Evacuees distribution in tunnel (f) Evacuees distribution at exit and entrance

Fig. 2. Natural draft

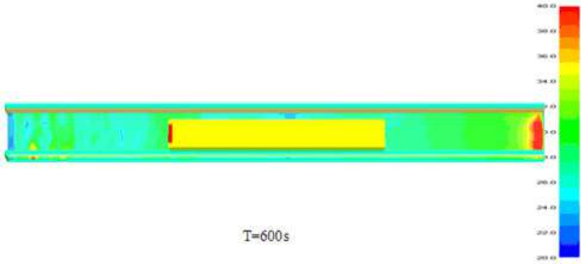


Fig. 3. Temperature at 1.7m height (t=600s)

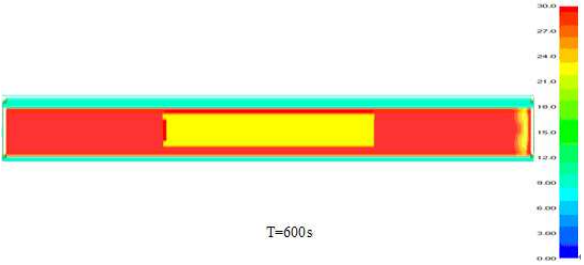


Fig. 4. Visibility at 1.7m height (t=600s)

From the Equ.(1) and the relationship between RSET and ASET, the RSET can be expressed as follows:

$RSET = t_{perc} + t_{resp} + t_{move}$ and RSET≤ASET

So,

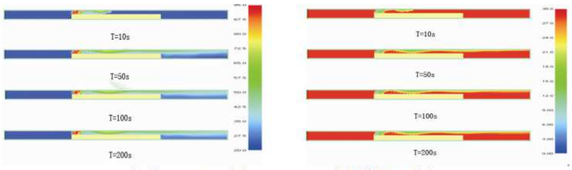
$$t_{move} \leq \text{ASET} - t_{perc} - t_{resp} \tag{4}$$

Referring to the table1 and thinking about the characteristics of subway tunnel, we choose $t_{perc} = t_{resp}$=30s, V=0.18m/s,B=0.55, and the safety factor is 1.3. According to the basic parameters of the metro vehicle, we calculate the ASET equal to 412.8s. Therefore, people can leave the fired tunnel within 170s.

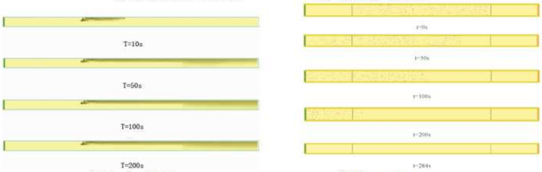
3.2.2 Mechanical draft

The simulated results of temperature visibility variation and smoke diffusion of the subway tunnel with mechanical draft are shown as Fig.5(a), (b) and (c). From the figures we can know that smoke diffusion tends to be stable after 50s. When the longitudinal velocity equal to 3.0m/s, back-flow of smoke does not happen, and the left area of fire source is smoke-free. From the Fig.5 (a) we can know that flame shift to the right of fire source and the offset distance is about 20m. From the Fig.5 (b) it can be known that the visibility is asymmetrical distribution and the visibility at the right of fire source about 20m is minimum.

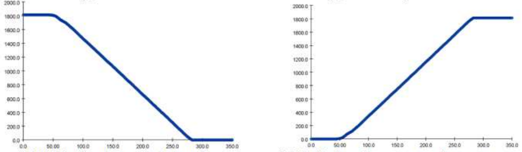
The simulated result of evacuation process is shown as Fig.5 (d), and the people distribution in tunnel or at exit and entrance are shown as Fig.5(e) and (f). The simulated results show that when t=0s, all people are around the train. When t=284s, the all evacuees have leaved the fire tunnel.



(a) Temperature variation (b) Visibility variation



(c) Smoke diffusion (d) Evacuation process

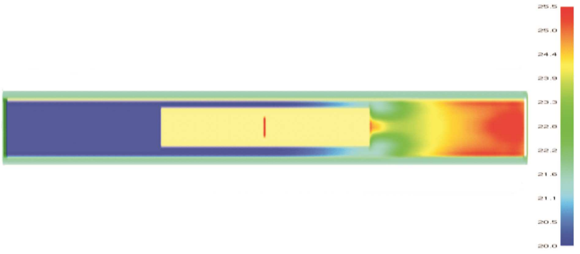


(e) Distribution of evacuees in tunnel (f) Distribution of evacuees at exit or entrance

Fig. 5. Mechanical draft

The temperature and visibility in the tunnel when t=600s are respectively shown as Fig.6 and Fig.7. The Fig.6 and Fig.7 show that it is safe if the evacuees leave the fire tunnel within 600s.

Just calculates the same as 3.2.1, we can calculate the ASET equal to 412.8s if the mechanical draft is used in the subway tunnel. From the simulated results it can be known that the evacuees can leave the fire tunnel within 284s.



T=600s

Fig. 6. Temperature at 1.7m height (t=600s)

T=600s

Fig. 7. Visibility at 1.7m height (t=600s)

4. Conclusions

From the simulated and calculated results we can know that the required safety egress times are 170s and 284s using natural draft and mechanical draft in the subway tunnel, respectively. The available safety egress times are all 412.8s either natural draft or mechanical draft. So, when the fire happened in this subway tunnel, people can be safely evacuated.

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