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Numerical Investigation on the Evacuation of Passengers in Metro Train Fire

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Abstract

This paper carried out the FDS+EVAC simulation to study the metro train fire with relatively large density of passengers. We defined the influencing factors through analyzing the contour of harmful gas concentration as well as smoke temperature. By comparing the Required Safe Egress Time (RSET) with Available Safe Egress Time (ASET), the distribution of evacuation safety was predicted. The results of no casualties reflect that the design of the Over Track Exhaust (OTE) system of the tunnel rail track and the lobby ventilation system is suitable, meanwhile, it may bring some guidance to design the new evacuation strategy for the metro station in fire scenery.

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Keywords: metro train fire, evacuation, ventilation

1. Introduction

In large cities, mass transit systems are in operation with big underground transports constructed [1]. The pedestrian flow in the metro station is consistently high. It is therefore important to carry out relevant researches on fire safety so that loss of property and huge casualties in case of fire can be minimized [2]. Fire threat is a major concern for metro station safety due to the presence of intensive crowds [3]. To achieve safe evacuation object in a metro fire is a process in which passengers are directed to safe zones as quickly as possible [4]. When a metro fire breaks out, the rapid spread of smoke may threaten the passengers and safe evacuation can be challenging. Some people in this condition may show panic behaviour and affect the movement of others [5]. The complex layout of metro station makes way-finding more difficult. Passengers in such deteriorating environment often attempt to evacuate through the way they entered, bypassing the alternative ways [6]. In the WTC 911 catastrophe, one reason for the delays in the evacuation process was that many people in the building could not find the emergency stairs, in spite of the safety exits being marked by emergency signs [7]. In 2005, Cairo, Egypt, a theatre had a big fire which caused huge casualties. Lots of people were pushed down when panic people rushed toward the gate [4]. It has practical significance to make emergency plans for safe evacuation of people during the fire. How to reduce the loss in public gathering places (for example metro) under the fire condition is worth noting. It is important to design the evacuation plan by taking into account the passengers' movement behaviour during the fire.

In recent years, a lot of researches have been done to discuss the characteristics of fire and evacuation by using different methods and many valuable and meaningful results are obtained. Zhan et al. [8] adopted FDS to simulate the interaction between the smoke flow and the water mist. Results showed that smoke suppression effect can be achieved greatest when the spray angel is 60°. Zheng et al. [5] proposed a modified Floor-Field model to analyze the effects of personnel density,

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exit width, fire location, smoke spread on evacuation dynamics. Nguyen et al. [9] presented a realistic model to optimize the evacuation strategies considering the level of visibility. They confirmed the great influence of smoke and blind evacuation strategy on the casualties. Zhang et al. [10] developed a probabilistic model for safe evacuation under the effect of uncertain factors during fire based on Latin Hypercube Sampling method. Results showed that the established model is more reasonable and suitable than the exiting methods. Sano et al. [11] presented an analysis of a stair evacuation model considering the impact of merging flows. They discussed the advantages and limitations of this model in relation to the traditional methods. However, the researches considering the safe evacuation under fire sceneries in the metro stations are relatively few.

A few researches specifically on metro fires have been carried out. Qu et al. [12] illustrated the common practice during the fire by referring to an example underground rail transit station. Wang et al. [13] simulated the metro fire and the evacuation of passengers in a tunnel by FDS+EVAC software. They found the evacuation used less time than other simulation methods. Gao et al. [2] introduced the influence of a dome on the fire-induced smoke control in a transit subway station. Zhong et al. [14] investigated the effect of piston wind on fire smoke propagation in a subway station. Results showed that the combination of lowering the altitude of smoke screens around staircases and enhancing the volume flux of pressurization at the hall layer are necessary. Giachetti et al. [3] used the PIV method to find the optimal ventilation strategy on fire-induced smoke in a confined model station. Ji et al. [15] conducted FDS simulations to explore the effect of ambient pressure on velocity and temperature field in a tunnel fire. Qu et al. [1] studied the influence of platform screen doors on the safe evacuation of passengers under the crowded situation. Galea et al. [6] tested the improved Active Dynamic Signage System (ADSS) in a full-scale evacuation trial. Results showed that the improved ADSS with voice alarm messaging doesn't contradict the signage system in the station and can successfully redirect 66% of passengers to the intended exit. These excellent studies can help us to better understand the subway fire, but the details about the safe evacuation in the case when the carriage catches fire need further study.

This paper studied the smoke spread and the safe evacuation of passengers in case of a metro train fire by using FDS+EVAC software, simultaneously, taking into account the structure features of the metro station. The assumptions made for the simulation and the results analysis were introduced in Section 2. The final conclusions were given in Section 3.

2. Numerical Simulations

2.1. The Fire Simulation

2.1.1. Scenarios

This section provided a novel simplified metro station model for the evacuation of all the passengers in the event of a metro train fire. The models of the metro station and the train were shown in Fig. 1 and the specific sizes were shown in Table 1. A set of assumptions were made in order to introduce the applicable scenery of the model.

Assumption 1. Ignoring some ancillary equipment (such as signs, trash, etc.).

Assumption 2. Smoke detectors had been installed in the metro station.

Assumption 3. The mechanical ventilation systems were installed in the model based on actual situation.

Assumption 4. Platform Screen Doors (PSDs) were set along the edge of the platform and two tunnels lied in both sides of the platform.

Assumption 5. The model allowed calculating the impact of ventilation vents and the smoke control equipment, regardless of the influence of fire suppression facilities.

Assumption 6. A suitcase burned up in the middle of the train car as an ignition source. The burning suitcase was made of PVC. As the pyrolytic material, the Heat Release Rate (HRR) of PVC closed to 7.5MW in this work. In addition, the power curve of the fire source adopted t^2 super-fast fire and the power growth coefficient of the fire source α used 0.19. There was no other thermal sources except the fire source.

Since the smoke generated by train fire in this case was mainly discharged through the OTE system of the metro tunnel, the amount of smoke exhausted was calculated according to the code for design of metro [18]. The smoke exhaust rate was set as 3m/s and six OTE vents were set on the top of each carriage.

2.1.2. Results

The safe environment for passengers to evacuate includes: at 2m height above the floor, smoke gas temperature is no more than 60℃, Carbon Monoxide (CO) concentration is no more than 500ppm and Carbon Dioxide (CO_2) concentration is far less than 2% [16]. Smoke temperature contour in the middle of the train at different time is shown in Fig. 2. CO concentration contour is shown in Fig. 3. CO_2 concentration contour is shown in Fig. 4. Wind velocity through two stairs at 360s is shown in Fig. 5.

It can be seen in Fig. 2, the highest temperature area concentrates in OTE vents above the fire source when the train