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Smoke Flow Temperature beneath the Ceiling in an Atrium-style Subway Station with Different Fire Source Locations

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Abstract

This paper is to investigate the smoke flow temperature beneath the ceiling in an atrium-style subway station. Numerical simulations were carried out in a full-scale model to study the temperature profile beneath the ceiling by considering different fire source locations. Results show that the maximum smoke temperature beneath the ceiling can be predicted using the three models developed by Alpert, Heskestad and McCaffrey. The choice of the most suitable model depends on the fire source location. For the longitudinal temperature distribution along the ceiling, if the disturbance region is far away from the fire source, the temperature profile can be well correlated by the Li's model. However, if the disturbance region is close to the fire source, the models proposed by Li and He should be used together. The temperature profile beneath the ceiling in this kind of subway station with different fire source locations can be obtained by the combination of these models.

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Keywords: subway station, fire source locations, temperature profile

Nomenclature

D	diameter of the fire source (m)
H	ceiling height (m)
L	one half of the ceiling width (m)
$\dot{Q}$	total heat release rate (kW)
$\dot{Q}_c$	convective heat release rate (kW)
r	distance from the plume centreline axis to the desired location (m)
T_∞	ambient temperature (K)
x^*	dimensionless distance from the fire source
z_0	virtual origin (m)
Greek symbols	
$\Delta T_{\max}$	maximum temperature rise beneath the ceiling (K)
ΔT_x	smoke temperature rise at the position x (K)

1. Introduction

The subway station is a relatively narrow and closed space and its structural style is similar with tunnel. Compared with numerous studies on the tunnel fire, the researches on the subway station fire are relatively few. Though most subway stations are equipped with fire suppression and smoke control facilities according to the regulations, the basic studies related to the subway station fire, such as the profile of the smoke temperature and velocity beneath the ceiling, are still lacking. To make

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the fire prevention design for the subway station more rational, some fundamental problems related to the pure effect of the fire-induced smoke need to be solved first.

The existed basic studies mainly focus on the smoke temperature profile under the ceiling of common subway stations. Ji et al. [1] established a simplified calculation method involving the Alpert equation and the correlation to predict the maximum smoke temperature under the ceiling when the fire occurred in the subway platform floor. Meng et al. [2] conducted experimental study on the effect of smoke screen height on temperature distribution of fire-induced flow beneath the platform ceiling of a subway station. A global formula was proposed to correlate the exponential power index of the temperature profile. Meng et al. [3] also investigated the smoke flow temperature beneath the tunnel ceiling for a train on fire stopping besides a subway station. The longitudinal temperature decay of the smoke flow was found to follow an exponential function for both types of platform-tunnel conjunction doors. Zhang et al. [4-5] developed a new physical model including the factor of metro train length to predict the length of smoke back-layering in the subway tunnel. Yao et al. [6] developed an empirical model to predict the smoke back-layering flow length in the subway tunnel fires with a vertical shaft in the upstream. Yao et al. [7] also improved an existing model to predict the maximum smoke temperature beneath the ceiling in the subway carriage and found that the prediction fitted reasonably well with the experiments when the dimensionless distance between the fire source and the carriage centre was less than 0.64. These excellent studies bring us a new perspective in understanding the smoke flow mechanism in common subway stations. However, the investigations on the smoke flow temperature and velocity beneath the ceiling of atrium-style subway stations are almost empty. Hence, it is equal important to do some basic studies on this kind of subway stations.

Compared to the common subway station, the atrium-style subway station can reduce the sense of oppression passengers feel in such enclosed space by improving lighting and offering visual beauty. Besides, some subway stations of this kind even build a dome at the top of the atrium to provide a light environment similar to that of the natural environment [8]. Passengers in such place can feel a sense of freedom and openness like that experienced in nature. However, since the atrium-style subway station can bring a comfortable environment to the passengers, the problems related to the fire-induced smoke control in the structure like this cannot be ignored. Duo to the large atrium space and relatively high density of passengers, the fire-induced smoke can easily spread to the whole space and cause heavy casualties if the effective smoke control measures are not taken. Thus, it is vital to know the smoke flow temperature and velocity profiles beneath the ceiling in order to properly set the smoke detection devices. This work focused on such basic studies to provide a reference for the engineering applications of fire detection, smoke control and safe evacuation in this kind of subway stations.

2. Numerical modeling

With the rapid development of the computational fluid dynamics (CFD), this kind of technology has been gradually applied to fire research field. Fire Dynamics Simulator (FDS) is such a CFD software and it solves numerically a form of the Navier-Stokes equations appropriate for low-speed, thermally-driven flow with an emphasis on smoke and heat transport from fires [9]. The accuracy of using FDS to predict the temperature and velocity field in the building with a fire source has been verified by many researchers [10-12]. Therefore, FDS was chosen in this work to carry out the numerical modelling of the fire happened in an atrium-style subway station.

The subway station model was consisted of the platform floor and the lobby floor. The chosen of the model size should be based on the practical engineering. Thus, the sizes of the platform floor and the lobby floor were the same as that used in reference [13], which respectively were 140 m × 12 m × 4.5 m and 140 m × 12 m × 4 m. Besides, four exits (6 m × 3 m) were located at the four corners of the lobby floor. As shown in Fig. 1a, there is an atrium (100 m × 8 m) connecting the platform floor and the lobby floor. With the existence of this atrium, the hot smoke induced by the fire can easily pass through it and spread upwards to the lobby floor, making personnel evacuation and fire rescue much more difficult [13]. The smoke curtain with 1.5m height was set under the ceiling of the platform around the atrium. Although this smoke curtain was designed to hinder the spread of the smoke between the two floors, the platform floor was split into five regions by the smoke curtain and some regions became similar to the corridor.

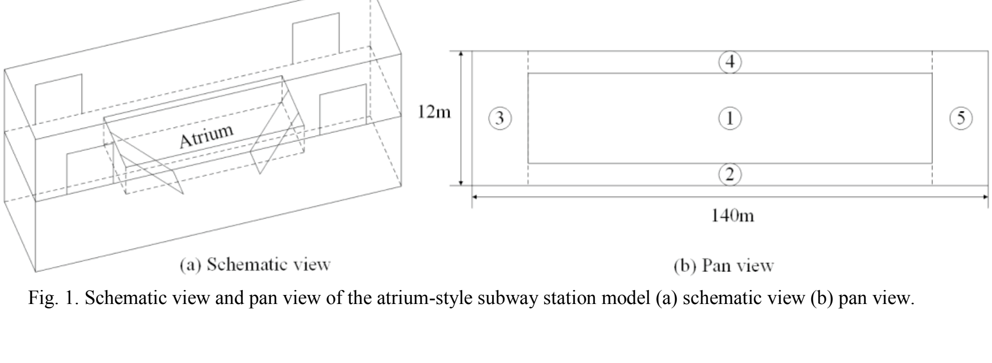

Fig. 1. Schematic view and pan view of the atrium-style subway station model (a) schematic view (b) pan view.