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Numerical study on the optimization of smoke ventilation mode at the conjunction area between tunnel track and platform in emergency of a train fire at subway station

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A B S T R A C T

To cope with fires in a subway station, ventilation systems are usually installed, which includes an air supply system and a smoke exhaust system. In case of a train fire, the operation of these ventilation systems needs to be studied in order to get optimal control of smoke propagation and provide better environmental conditions for personnel evacuation. In this paper, CFD simulations are carried out by Fire Dynamics Simulator (FDS) to study the effectiveness of different ventilation modes in case of a train fire in a subway station. The temperature and visibility contours are computed as to compare the performance of various ventilation modes for subway stations with full-seal Platform Screen Door (PSD) or half-height safety door. Results show that appropriate activation of the air supply system can improve the efficiency of the ventilation system in smoke control, and vice versa. It is better to activate the lobby air supply system and meanwhile close the platform air supply system. As for the exhaust system, it is necessary to activate the platform exhaust system and the Over Track Exhaust (OTE) system, and it is better to deactivate the Under Platform Exhaust (UPE) system. The optimization strategy of the ventilation mode for subway stations with full-seal PSD is similar to that for subway stations with half-height safety door. With the help of the additional smoke barrier, smoke propagation in a subway station can be well controlled. The results in the paper may serve as a useful reference for the smoke control design in case of subway train fires.

1. Introduction

Fires have become a significant threat to the safety of subway transportation. Because of its special spatial structure compared to buildings above ground, fires in subway usually cause more severe consequences, such as more people killed and more property losses. On February 18, 2003 (Hong, 2004; Park, 2004), an arsonist sets fire to one of the cars of a six-carriage train stopping at Jungangno Station in Daegu, South Korea. Within minutes, the fire engulfed the entire train and another train that entered the station from the opposite direction. The tragedy left about 200 dead and 150 injured. When a train is on fire, the usual way is to drive it to the front subway station for personnel evacuation. During the evacuation process, the most immediate threat to passengers' lives is not direct exposure to fire, but smoke disturbance and smoke inhalation because it decreases the visibility of the escape route and contains hot air and toxic gases (Chen et al., 2003; Purser, 1988; Roh et al., 2009). In addition, the routes for passengers' evacuation, firemen's rescue and for the movement of hot and toxic gases are usually the same, which makes the passengers' evacuation and firemen's rescue much more difficult. Therefore, smoke control systems are quite necessary in order to obtain a safe evacuation path that is free of smoke.

At subway station, smoke control systems are usually composed of multiple mechanical smoke control systems, such as the air supply system, the Over Track Exhaust system (OTE), the Under Platform Exhaust system (UPE), the smoke exhaust system at the platform and the Tunnel Ventilation Fan system (TVF). Usually, smoke barrier and smoke screen are also needed as additional smoke control setup in order to improve the effectiveness of the smoke control systems (Chen et al., 2003). What is more, platform screen door systems have been used in newly built subway stations as to provide passengers with more comfortable indoor air conditions.

Researchers have already carried out studies on the smoke control systems at subway stations and on the effect of platform screen door on smoke control systems. In Park's study (Park et al., 2006), it is shown that the capacity of exhausts installed at the subway station exerts a significant influence on the movement of smoke in case of a fire. In Rie's work (Rie et al., 2006), a study of optimal ventilation mode for the smoke control of subway station

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Nomenclature

c_p	constant pressure specific heat (kJ/kg/K)
C_s	Smagorinsky constant (LES)
D	diffusion coefficient (m^2/s)
D^*	characteristic fire diameter
f	external force vector (excluding gravity) (kg/s^2/m)
g	gravity acceleration constant (m/s^2)
h	enthalpy (kJ)
k	thermal conductivity (W/m/K)
$\dot{m}_l'''$	mass production rate of species l per unit volume (kg/s/m^3)
p	pressure (Pa)
Pr	Prandtl number
$\dot{Q}$	heat release rate (kW)
q_r	radiative flux (kW/m^2)
$\dot{q}'''$	heat release rate per unit volume (kW/m^3)
Sc	Schmidt number
t	time (s)
u	velocity vector (m/s)
u_{ijk}	velocity vector in x-axis direction (m/s)
v_{ijk}	velocity vector in y-axis direction (m/s)
w_{ijk}	velocity vector in z-axis direction (m/s)
Y_l	mass fraction of lth species
ρ	density (kg/m^3)
ρ_∞	density of ambient (kg/m^3)
μ	dynamic viscosity (N S/m^2)
τ	viscous stress tensor (kg/s^2/m)
δx	dimensions of the smallest grid cell in x direction (m)
δy	dimensions of the smallest grid cell in y direction (m)
δz	dimensions of the smallest grid cell in z direction (m)

fires is conducted based on three different tunnel fan operation scenarios. However, in his study, only fans in the tunnel are involved, the ventilation systems at the platform and the lobby floor are not considered. Chen's (Chen et al., 2003) study shows that when a train is on fire, the smoke generated by a fire of 10 MW can be well controlled if a suitable scheme for smoke control is applied. His study also reveals that when a fire occurs on the train, the existence of platform screen door helps to restrict the smoke within the rail space and the tunnel, and to make smoke control much easier than that without a PSD. In Chen's study, the TVF, UPE ventilation systems are all considered to be activated, however, other smoke control systems, such as the air supply systems, had not been considered together.

When a train is on fire and stops at a subway station, all doors of the train and those of the PSD are open for passengers' evacuation. At this time, the tunnel and the platform are connected in space. Smoke spills from the train carriage and spreads to the platform and the tunnel. Under such circumstances, smoke control systems of the tunnel track and those of the platform are both to be considered. However, in case of a train fire, the operation of various smoke control systems of a subway station has rarely been conducted.

In this paper, the Fire Dynamic Simulator (FDS version 5) code is used to investigate the effect of different ventilation modes on smoke control of train fires. The temperature and visibility field are computed when different ventilation operation scenarios are applied. An optimal ventilation mode is finally suggested based on the computational results, as to serve as a useful guideline to smoke control of train fires at subway station.

2. CFD modeling

2.1. The physical model

The subway station for the present study is considered to represent a typical subway station with two floors under the ground, as shown in Fig. 1. The first floor under the ground is the lobby floor, with size of 140 m × 12 m × 4 m. The second floor under the ground is the platform floor, with size of 140 m × 12 m × 4.5 m. Especially, there is an atrium (80 m × 8 m) at the station. However, with the existence of the atrium, the platform floor and the lobby floor are connected in space and hot smoke induced by a fire can easily pass through it and spreads upwards to the lobby floor, making personnel evacuation and fire rescue much more difficult. There are four exits, with size of 6 m × 3 m, at the four corners of the lobby floor.

The railway track is located at one side of the platform floor, with size of 180 m × 5 m × 6 m. The train at the station is composed of 6 carriages, with total size of 140 m × 3 m × 2.75 m. Each carriage has 5 doors and there are total 30 doors installed in the train, with size of 2 m wide × 2.2 m high. A simulated fire source is placed at the center of the train carriage. The fire properties are set according to previous researches or the default values in FDS User Guide. The Heat Release Rate of the fire source is 10 MW (Chen et al., 2003) and the fraction of fuel mass converted into smoke particulate is denoted as y_s and is set to be 0.1 for the simulation (Hu et al., 2007a,b, 2009; Lin et al., 2008). In FDS, by default, the RADIATIVE_FRACTION is 0.35 for an LES simulation.

Platform Screen Door (PSD) is installed at the edge of the platform, as shown in Fig. 2. It is a vertical wall usually made of transparent material such as reinforced plexiglass. For full-seal PSD, the vertical wall is as tall as the platform. That is to say, when full-seal PSDs are closed, spaces between the platform and the tunnel rail track are completely separated, as in Fig. 2a. While, for half-height PSD, the wall is usually 1.2–1.5 m above the platform floor. When the half-height PSDs are closed, the platform and the tunnel track are still connected in space, as in Fig. 2b. So, this kind of door is also called as half-height safety door as a difference from full-seal platform screen door. For the present study, only one side of the platform is considered to be installed with PSDs, and the other side is supposed to be closed and completely separated from the railway track.

As shown in Fig. 3, the mechanical ventilation systems, considered in the study, are composed of: (1) the lobby air supply system is a series of air inlets located along the ceiling of the lobby floor, as shown in Fig. 3a; (2) the platform air supply system is also a series of air inlets but under both ends of the platform ceiling, as shown in Fig. 3b; (3) the smoke exhaust system at the platform is a series of air outlets under the ceiling of the platform, as shown in Fig. 3b; (4) the Over Track Exhaust system (OTE) is a series of openings along the ceiling of the tunnel, exhausting smoke in the tunnel track, as shown in Fig. 3b; (5) the Tunnel Ventilation Fan system (TVF) is located in the tunnel quite near the two ends of the platform, extracting smoke in the tunnel, as shown in Fig. 3b; (6) the Under Platform Exhaust system (UPE) is a series of openings under the platform, as in Fig. 3c. Under normal circumstances, the air supply systems in the platform floor and the lobby floor are both