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Optimization of switch modes of fully enclosed platform screen doors during emergency platform fires in underground metro station

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A R T I C L E I N F O

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A B S T R A C T

Fire is a major hazard in an underground metro station. Faced with challenges from fires in metro stations, platform screen doors (PSDs) are usually installed on the ground, which are critical to passengers' life safety. In case of a platform fire, in order to get optimal control of smoke and provide better environmental conditions for evacuation, the operation of those PSDs needs to be systematically studied. In this work, Fire Dynamics Simulator (FDS) was used to investigate the smoke exhaust effect during fires in underground island-type platform under twenty-four different PSD switch modes. The parameters that influence evacuee life safety, such as temperature and visibility contours at the stair entrance, were computed to compare the performance of different switch modes for the underground metro station with fully enclosed PSDs. The simulation results show that the optimization of the PSD switch modes in the underground metro station depends significantly on the cooperation of the air supply system in the lobby floor, the air exhaust system in the platform floor and the tunnel. Three potential fire sources in the platform floor have been studied. When the fire source is in the center of the subway platform, it is better to open four end doors and 12 PSDs in one side, or open all PSDs in one side during the developing stage of fire. As for its stable stage of fire, it is better to open four end doors or all PSDs in one side. When the fire source is near the ends of the platform, it is better to open all PSDs in one side or open four end doors during the developing stage of fire. As for its stable stage of fire, it is better to open all PSDs in both sides near the fire sources. Those results can provide some guidance to the smoke control design in case of platform fire in the underground metro station.

1. Introduction

With the rapid development of the world economy and the acceleration of urbanization, metro has become an important tool to solve the problem of traffic congestion in large and medium-size cities. In China, the metro line systems have transported over 16 billion people during 2016 and increased by 16.6% compared with that of 2015. Particularly in Beijing, the passenger traffic reached to 3.66 billion people and achieved an average daily traffic over 10 million person-times in total in 2016, which set its highest record of average daily passenger transportation volume. Correspondingly, the length of China's subway lines is tremendous. The length of metro line under operation has increased gradually in recent years in many cities in China such as Beijing, Shanghai, Tianjin, Chongqing, Guangzhou, Shenzhen, Wuhan, Nanjing, Chengdu, etc. More specifically, as of December 31, 2016, the subway line that are open to the public amounts to a total length of 4152.8 km in Mainland China. In addition, the construction of large-scale metro is still ongoing in many cities where the total length of metro under construction is 5636.5 km and the line length reaches 7305.3 km in total (China Urban Rail Transit Annual Report Task Force, 2017).

Metro is an indispensable and convenient transportation mode in cities of high population density. However, on the other side, the metro line system also brings a serious challenge for fire protection (Wang, 2011). Fire, as a major risk to the safety of subway transportation, has caused the death of many people and great property losses. For example, on November 18, 1987, a fire that occurred in King's Cross Station in London, killed 32 and injured more than 150 people (Shi et al., 2012). On October 28, 1995, a server subway fire occurred in Baku Azerbaijan, which resulted in the death of 289 people and the injury of 265 people (Luo et al., 2014; Gao et al., 2012). On February 18, 2003, a disastrous subway fire was deliberately set by an arsonist

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and the fire spread quickly to all of the six coaches of the train in two minutes. This accident destroyed two trains and caused large casualties of 192 people and the injuries of 148 people in Daegu, South Korea (Gao et al., 2012; Tsujimoto, 2003; Tsukahara et al., 2011). One of the most important factors for many casualties in such fires is that smoke control systems did not have adequate capacity and hence the poisonous smoke spread quickly and uncontrollably through the whole area of the subway station (Roh et al., 2009). It is well known that smoke is the most dangerous element to cause death and injury in a fire (Black, 2009). Therefore, to ensure the safe evacuation of people, it is worthwhile to study the ventilation system in case of fire.

Underground space fire safety has been such a hot topic in recent years, for which many studies have been carried out on life safety in underground metro stations or tunnels. At the very beginning, many researchers focused on fire-induced smoke movement, mechanical ventilation, smoke temperature and smoke layer using mathematic analysis, zone model, field model and experimental studies in tunnels and metro stations (Thomas, 1958; Heselden, 1976; Brandies and Bergmann, 1983; Hwang and Wargo, 1986; Vantelon et al., 1991; Simcox et al., 1992; Charters and McIntosh, 1995; Chow, 1993; Chow, 1996). These studies produced some empirical equations of fire-induced smoke movement and heat transfer, such as the stratified evolution of the smoke backflow and the behavior of thermally generated stratified layers in long and narrow space. More importantly, researchers came to realize that the mechanical ventilation system played a very important role in controlling the smoke in tunnels and underground metro stations. Thereafter, with the development of computer technology, a large number of numerical simulation studies of underground metro stations were carried out to study the efficiency and to find the better scheme of mechanical ventilation (Cheng et al., 2001; Chen et al., 2003; Park et al., 2006; Rie et al., 2006; Roh et al., 2009; Jia et al., 2009; Li et al., 2016; Meng et al., 2014; Gao et al., 2012; Ding et al., 2016). A hypothetical fire and its evacuation in Taipei Mass Rapid Transit System have been simulated by Cheng et al. using MFIRE. Cheng found that conducting the "push-pull" ventilation model can exhaust the high temperature air and smoke out of the underground facilities efficiently once the fire broke out (Cheng et al., 2001). After this study, Chen et al. studied the effectiveness of the smoke control scheme of Gong-Guan metro station with Fan for Tunnel Ventilation (TVF), Under Platform Exhaust system (UPE) and smoke exhaust gate in the lobby floor by using Computational Fluid Dynamics (CFD) techniques and found that the smoke will be well controlled under different fire sources with the ventilation scheme recommended by the authors (Chen et al., 2003). At this stage, many scholars gradually began to use fire simulation software to study the ventilation of subway fire smoke. Due to the high efficiency and low cost of fire simulation, a large number of scholars subsequently conducted simulation on smoke ventilation in subway fires, in cooperation with experimental research. In 2006, the numerical prediction of smoke movement in a metro station equipped with mechanical ventilation had been further studied by Park et al. and they found that exhaust capacity exerts a significant influence on heat transfer and smoke movement (Park et al., 2006). In the same year, experiments and corresponding Fire Dynamics Simulator (FDS) analysis were conducted by Rie et al. to investigate the efficiency of three kinds of mechanical ventilation in case of fire and they got an optimal ventilation mode (Rie et al., 2006). Gao et al. compared two different kinds of mechanical ventilation and found out the better vitalization mode for smoke control (Gao et al., 2012). In Meng's study, the temperature and visibility contours were computed to compare the performance of various ventilation modes for a metro station with two kinds of Platform Screen Door (PSD). Meng found that appropriate activation of the air supply system can improve the efficiency of smoke control (Meng et al., 2014). Ding et al. studied four kinds of switch modes of manually-controlled secondary door (MSD) based on Large Eddy Simulation (LES) and found out that only by switching the manually-controlled secondary door cannot meet the need of smoke control in fire (Ding et al., 2016). After this study, Li et al. simulated four switch modes, including opening four end doors and PSDs. The results of this study show that it is better to use different switch modes during different stages of fire development (Li et al., 2016).

In previous studies, the different mechanical ventilation modes and switch modes have been studied to control the smoke in the underground metro tunnels. However, those studies rarely considered how the mixing switch modes of end doors in both sides and how PSDs influence the efficiency of smoke control for different locations of fire source. In this study, FDS was applied to investigate the smoke exhaust effect during fires in underground island-type platform for different PSD switch modes. The parameters that influence evacuee safety at the stair entrance were computed to compare the performance of different switch modes for an underground metro station with fully enclosed PSDs.

2. Simulation method

2.1. The physical model

The metro station discussed in this study is a typical underground metro station with two stories constructed in Chongqing and located close to the central business district, as shown in Fig. 1. The first floor is the lobby floor, with the dimensions of 82 m × 20 m × 7 m. The second floor underneath it is the platform floor, with the dimensions of 113 m × 12 m × 4 m. There are smoke barriers that are 1 m high situated around the stairs. Three exits to the ground (safe region) lie in the corners of the lobby floor each with the dimensions of 6 m × 2.45 m. Two tunnels are located on the both sides of the platform, which is a typical island-type platform. In this metro line, it is running a typical B-type subway train that is composed of six carriages with a total size of 114 m × 2.8 m × 2.6 m. Each carriage has 4 doors and there are 24 doors installed in the train in total each with the dimensions of 1.2 m wide and 1.8 m high. The PSDs are installed on the edge of the platform floor. The PSDs are embedded within a vertical wall and this wall is usually made of transparent materials such as plexiglass. If all of the PSDs are closed, the tunnels and the platform are completely separated. Additionally, obstructions such as bearing columns and rooms are considered in this study, which will affect the spread of smoke within the area shown in Fig. 1.

As shown in Fig. 2, the mechanical ventilation system in current study within the metro station is composed of: (1) two lines of the lobby air supply system located on the ceiling of the lobby floor, which are shown in Fig. 2a; (2) the platform air supply system in the platform floor, which is shown in Fig. 2b; (3) one line of smoke exhaust system at the lobby and a series of outlets under the ceiling of the lobby, which

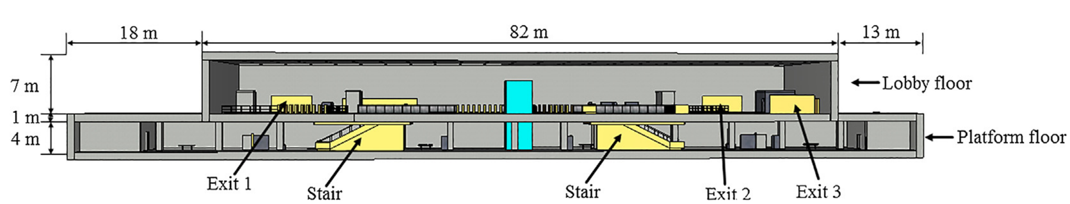

Fig. 1. Geometry of the underground metro station.