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Numerical studies on the smoke control by water mist screens with transverse ventilation in tunnel fires

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ABSTRACT

Emergency ventilation systems are commonly used for smoke control during tunnel fires. For the transverse ventilation system, high efficiency for fire safety could be obtained by confining the smoke within certain zones. In this paper, a new system with simultaneous water mist screen and transverse ventilation system (WMSTV system) is proposed. In the WMSTV system, water mist screens are used to confine smoke from spreading widely, which assists the smoke exhausting process of the transverse ventilation system. Numerical method is used for investigation in this paper. The effects of natural and transverse ventilation systems without water mist are also investigated for comparison. Numerical results show that the WMSTV system can confine the fire and smoke effectively and the environment inside the confined zone would be suitable for occupants evacuation and firefighting. The system can be regarded as a feasible strategy for smoke control in tunnels.

1. Introduction

The tunnel fire safety has attracted more and more concerns after a number of severe fire accidents occured all over the world (Barbato et al., 2014). In tunnel fires, the smoke would spread longitudinally and descend to the ground at locations away from fire origin, which might block the escape route. Consequently, safety evacuation of occupants may be affected by high temperatures and toxic gases. To reduce the risk, previous researches have been carried out to study the ventilation systems in controlling the smoke spread in tunnels.

Li and Chow (2003) investigated the performances of several configurations of ventilation systems and highlighted both the advantages and disadvantages. Vauquelin and Megret (2002) carried out a series of experiments to investigate the effectiveness of a two-point extraction system and its efficiency the in a 5 m high and 10 m wide tunnel. These researches have pinpointed that maintaining the smoke in a restrained zone would be a better strategy to enhance the ventilation system efficiency.

According to the previous researches, to improve the transverse ventilation efficiency, a long tunnel should be divided into several fire compartments using flexible devices. Bettelini et al. (2012) evaluated all possible applications of flexible device for smoke control in road tunnels, including massive doors, water and air curtains and inflatable plug which could be used in similar manners. Hu et al. (2007, 2008) studied the confinements of smoke and carbon monoxide by air curtains using scaled experiments and numerical method. Felis et al. (2010) and Severino et al. (2013) investigated the effect of air curtain, named as "double stream-twin jets (DS-TJ)", to prevent the heat propagation of fire in a corridor-like geometry. The DS-TJ system consists of 2 twin plane jets supplying respective hot air from the smoke area and fresh air from the protected area. Amano et al. (2006) and Murakami et al. (2007) proposed water screen and water spray systems for tunnels. The water screen system of special nozzles with a diameter of 200 μm arranged in rows were used to form the fire compartment to prevent smoke spread. A water-based compartmentation system has been developed by APT (McCory, 2008), which is named as water shield mitigation system as shown in Fig. 1(a). This system has been tested in both scaled and full-scale tunnels with longitudinal ventilation for fires up to 20 MW. The test results showed that the compartmentalization was effective on the upstream side but inefficient on the downstream side, and the forced airflow significantly affected the water shield mitigation system. Sun et al. (2016) discussed the effectiveness of a water system in preventing smoke spread and reducing temperature in a reduced-scale tunnel with and without forced

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Nomenclature

c_p	constant pressure specific heat (kJ/(kg K))	$\dot{q}'''$	heat release rate per unit volume (kW/m^3)
D	diffusion coefficient (m^2/s)	T	temperature (K)
D^*	characteristic fire diameter (–)	T_0	temperature of ambient (K)
d	droplet diameter (μm)	t	time (s)
d_m	median droplet diameter (μm)	u	velocity vector (m/s)
f	external force vector (excluding gravity) (kg/s^2/m)	Y_l	mass fraction of lth species (–)
g	acceleration of gravity (m/s^2)	ρ	density (kg/m^3)
h	enthalpy (kJ)	ρ_0	dencity of ambient (kg/m^3)
k	thermal conductivity (W/m/K)	τ	viscous stress tensor (kg/s^2/m)
$\dot{m}'''$	production rate of lth species per unit volume (kg/s/m^3)	γ	empirical constants (–)
Q	heat release rate from fire (kW)	σ	empirical constants (–)
q_r	radiative heat flux vector (kW/m^2)		

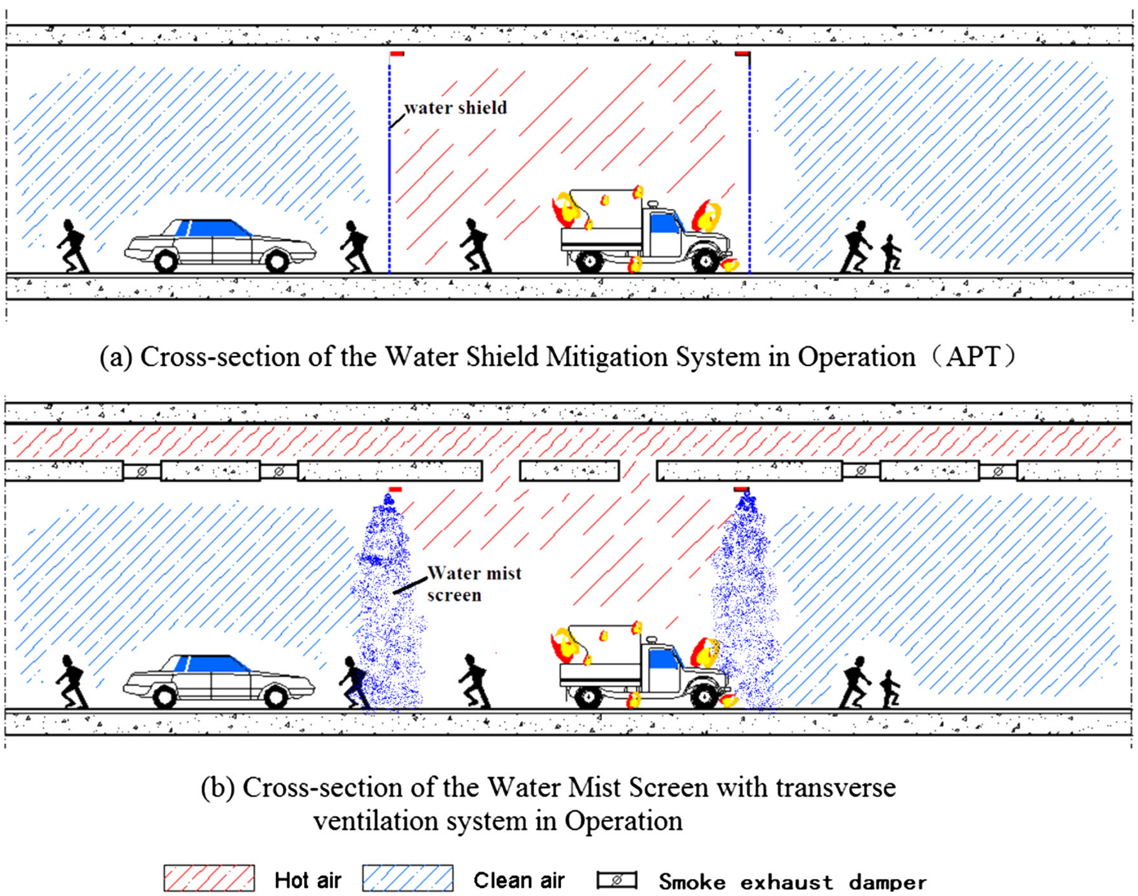

Fig. 1. Sketch of two types of compartmentalization in tunnel.

longitudinal ventilation. The results indicated that the water system can reduce the temperature of hot gas and prevent the smoke from spreading when the longitudinal ventilation is absent.

From the literature review, it can be concluded that most previous studies focused on the smoke compartmentation in tunnels while the smoke ventilation was not taken into account. In practice, transverse ventilation and water mist screens should be used simultaneously to control smoke spread. Van den Horn (2004) argued that the transverse ventilation might significantly complement and improve the performance of water shield mitigation system. However, the effectiveness of transverse ventilation added to the water system was not studied in depth.

In this study, a new smoke control system (WMSTV system) is proposed. The system is composed of water mist screens and transverse ventilation system as shown in Fig. 1(b). The water mist screen is not directly above the fire source, instead, it would be used to confine the smoke and fire in a restrained zone. The difference of the water shield mitigation system by McCory (2008) and the current system is that the smoke in the confined zone can be extracted by the transverse ventilation if WMSTV is used. Then the smoke can be quickly removed from the confined zone and the environment ought to be clean and safety for evacuation and firefighting out of the confined zone.

The aim of present study is to investigate the effectiveness of the WMSTV system. Numerical method with large eddy simulation model (LES) has been used in this research. The traditional natural ventilation system and transverse ventilation system without water assistance are used for comparison of the effectiveness WMSTV.