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Experimental study on thermal and smoke control using transverse ventilation in a sloping urban traffic link tunnel fire

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ABSTRACT

A set of full-scale experiments was conducted to study thermal and smoke control strategies using transverse ventilation system in a sloping urban traffic link tunnel (UTLT). Results showed that it is not the case that the slower the smoke spread longitudinally, the better the smoke being controlled. For transverse ventilation, within the smoke extraction compartment, the faster the smoke spread to the exhaust vents the faster the smoke being extracted from the tunnel. More importantly, the operation of the exhaust and supply vents for transverse ventilation in real time should take the effect of tunnel slope into consideration. For tunnel with a slope going uphill from upstream to downstream, supplying air from the downstream is recommended while supplying air from the upstream or directly to the fire located smoke compartment should be avoided. Additionally, for a given total smoke exhaust volume flow rate, increasing the number of exhaust vents is an effective way of controlling the smoke layer interface height. For the kind of tunnel as studied at hand, open the exhaust vents in the fire located compartment and its downstream smoke compartment is recommended.

1. Introduction

Fire safety in tunnel has attracted large public attentions from a relevant number of tragic events such as the fire in the Mont Blanc Tunnel (1999) between Italy and France (Duffé and Marec, 1999), the Kaprun tunnel fire (2000) in Austria (Meyer, 2003), the Yanhou tunnel fire (2014) in China (Wang et al., 2016) and several other accidents all around the world (Beard and Carvel, 2005; Ingason et al., 2014). Tunnel fire safety issues are becoming more and more complex since new challenges to tunnel fire safety have emerged in the growing number of new tunnels being constructed worldwide (Ingason, 2016). For instance, the urban traffic link tunnel (UTLT) studied at hand, is a new type of traffic system usually built under the ground of a CBD area with dense population. This traffic system typically consists of a looped main tunnel and several adjoining ramp tunnels (Hua et al., 2011). Fire safety issues for this type of road runnel will be discussed in the following.

Smoke has been reported as the most fatal factor in these tunnel fires. When a fire occurs in a tunnel, smoke control is crucial since the smoke will reduce visibility and can cause deaths by asphyxiation (Ji et al., 2011). Thermal and smoke control strategies in tunnel has been extensively investigated during the past, labeling its role in human evacuation and fire rescue (Fridolf et al., 2014; Seike et al., 2017).

Mechanical ventilation systems have to be used in order to control the fire-induced smoke (Vauquelin and Mégret, 2002). Practically, the choice of a ventilation system mainly depends on the tunnel length and its traffic mode (bidirectional and unidirectional) and can be mainly split into two categories (Ingason et al., 2014): the longitudinal ventilation and the transverse ventilation (see Fig. 1).

Longitudinal and transverse ventilation have been identified as the two most prevalent ventilation strategies for conventional tunnels (Chen et al., 2013; Fan et al., 2013). Longitudinal ventilation is suitable for unidirectional tunnels with low traffic and low possibility of congestion (Vauquelin, 2008). In case of fire, the mechanical ventilation (jet fans) is used to push the whole fire-induced smoke downstream from the fire source location. Thus, the upstream of the fire source is considered safe for evacuation in this case. Transverse ventilation is required for bidirectional tunnels and unidirectional tunnels with high possibility of congestion (Vauquelin, 2008). The objective of transverse ventilation system is to confine and extract the smoke over a

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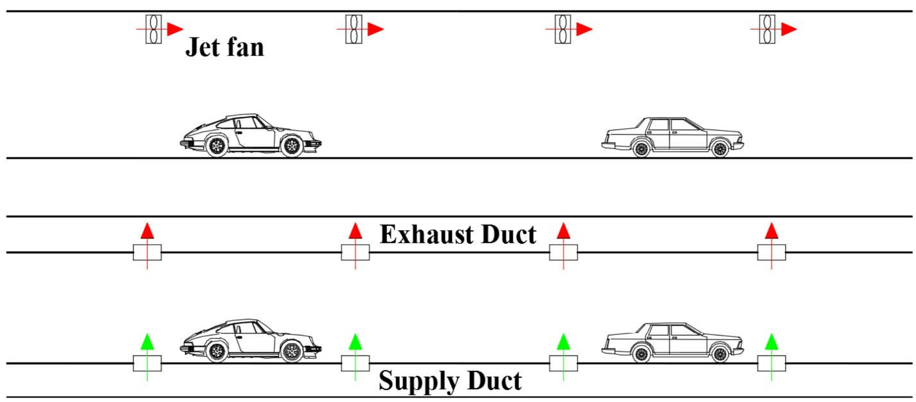

Fig. 1. A schematic diagram of longitudinal ventilation system (top) and transverse ventilation system (bottom).

longitudinal distance as short as possible. Therefore, people can be evacuated in both tunnel directions. Noted, a combination effect of longitudinal ventilation and transverse ventilation on the tunnel fire smoke flow behavior and temperature profile have also been studied (Chen et al., 2015; Hu et al., 2014; Tang et al., 2017).

Recently, the transverse ventilation has been used in a new type of tunnel system, i.e., the urban traffic link tunnels (Du et al., 2016, 2015; Guo et al., 2013; Hua et al., 2011). In recent years, due to rapid urbanization, UTLT have been increasingly emerged rapidly to relieve traffic pressure. This complex network system is different from an ordinary road tunnel and possesses a higher potential risk of fire in the following aspects (Du et al., 2016, 2015): (1) UTLT is not a sole tunnel but a complex network system with at least one circinal tunnel and various branch tunnels, which cause complicated smoke exhaust and air supply system design and operation strategies. (2) UTLTs are usually built deep underground with large slopes and narrow section due to the limitation of space. This increases the difficulties of fire extinguishment and fire rescue for fire fighters. (3) Multiple routes with high density of vehicles could increase the possibility of fire accidents in arbitrary positions with different circumstance, e.g. uphill or downhill, thus increase the complexity for the operation of centralized fire smoke control system.

This has been indicated as well in Du et al. (2016, 2015), Guo et al. (2013) and Hua et al. (2011), that both the design and operation of normal and emergency ventilation in a UTLT are considerably more complex than those in conventional tunnels. The growing number of new tunnels being constructed worldwide brings new challenges to tunnel fire safety (Ingason, 2016). Therefore, the application of smoke control in the UTLT fire is worthy of further investigation due to the remarkable differences between the aforementioned UTLT and common road tunnel.

Fewer studies have been dedicated to fire smoke control in UTLT. Hua et al. (2011) conducted a series of numerical simulations on the CBD UTLT in Beijing. An optimal smoke control strategy for a designed fire scenario is obtained based on a hybrid ventilation system. Guo et al. (2013) conducted a study on the smoke control system in the CBD UTLT in Wuhan using CFD and small-scale experiment. The effectiveness of the natural and semi-transverse ventilation system is assessed. Du et al. (2015) investigated the design method of longitudinal ventilation system for smoke control in UTLT with numerical simulations. A methodology for the design of longitudinal ventilation system in UTLT was proposed. Only a recently published research could be found for

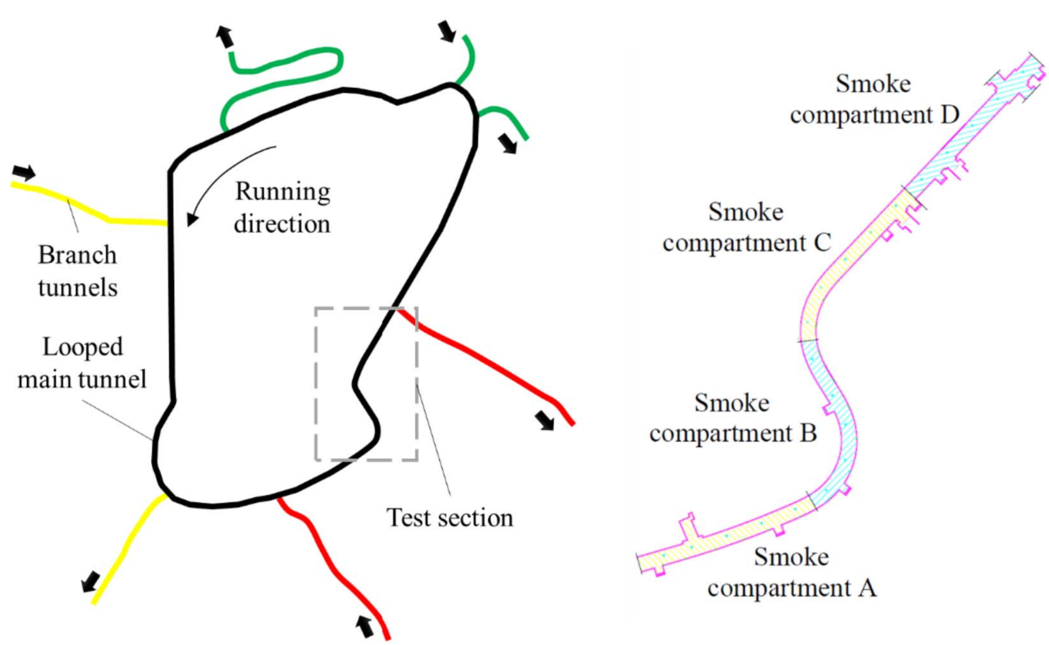

Fig. 2. The plan view of the UTLT of PLM (left), zoom-in sketch of the test section (right).