Applied Thermal Engineering 96 (2016) 490–500

Contents lists available at ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Research Paper

Performance evaluation of longitudinal and transverse ventilation for thermal and smoke control in a looped urban traffic link tunnel

Tao Du [a], Dong Yang [a,b,*], Shini Peng [a], Yingli Liu [a], Yimin Xiao [a]

[a] Key Laboratory of the Three Gorges Reservoir Region's Eco-Environment, Ministry of Education, Chongqing University, Chongqing 400045, China
[b] National Centre for International Research of Low-carbon and Green Buildings, Chongqing University, Chongqing 400045, China

HIGHLIGHTS

- We study the adaptability of longitudinal and transverse ventilation for UTLTs.
- The key design parameters of the two ventilation modes are re-examined.
- Experiments are performed to investigate the smoke control efficiency.

ARTICLE INFO

Article history:
Received 3 July 2015
Accepted 13 November 2015
Available online 10 December 2015

Keywords:
UTLT
Smoke control
Experiments
Longitudinal ventilation
Transverse ventilation
Smoke exhaust

ABSTRACT

The complex structure of the urban traffic link tunnel (UTLT) exacerbates fire accident risk and increases the difficulty of smoke control, especially for a UTLT with looped tunnel systems. The applicability of the traditional tunnel smoke control methods, e.g., transverse ventilation and longitudinal ventilation, needs further investigation for UTLTs. Experiments were conducted in a small-scale model to investigate the effectiveness of both two ventilation modes for a looped UTLT. In a longitudinally ventilated UTLT, the critical velocities, as the minimal air velocities for preventing smoke infiltrating into the regions upstream of the fire and entering the downstream tunnel branches that are adjacent to the smoke discharge route, should be guaranteed. Multiple operational modes of longitudinal ventilation could be feasible for achieving the desired performance of smoke control. For transverse ventilation, both the effects of the exhaust flow rate and the air supply rate are investigated. To confine the smoke in the tunnel branch where fire occurs, an effective exhaust flow rate could be twice the smoke production rate. Forced air supply could be unnecessary for a UTLT due to the abundance of natural air supply routes. Longitudinal ventilation leads to lower smoke flow temperatures than transverse ventilation does in UTLTs.

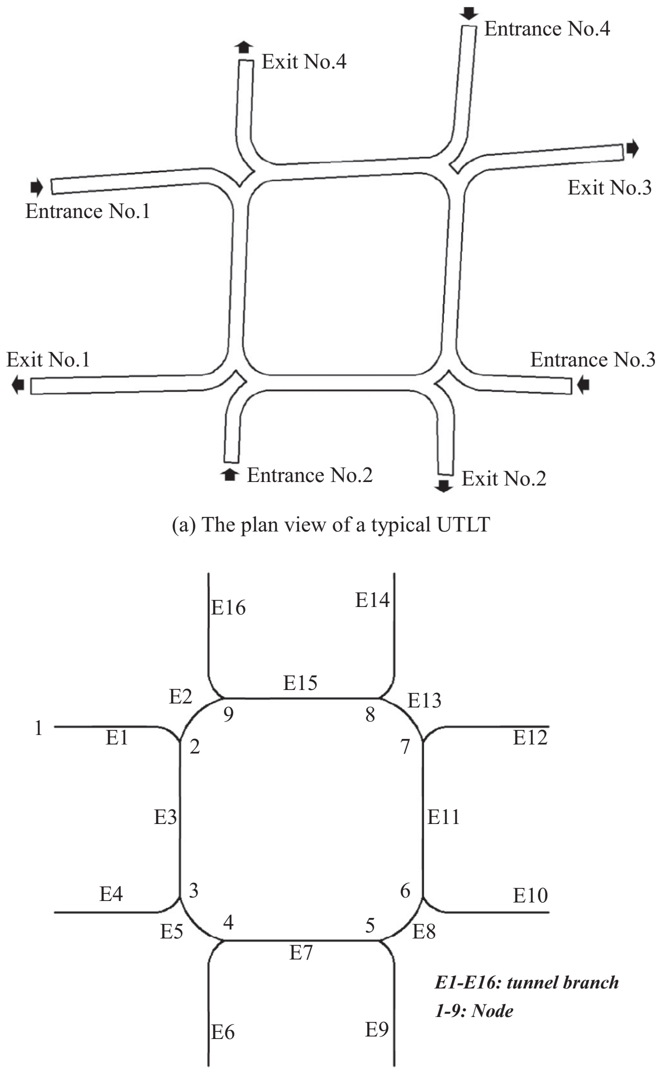
1. Introduction

To relieve traffic pressure, urban traffic link tunnels (UTLTs) have been increasingly merged into urban traffic systems, especially in rapidly developing countries, e.g., China [1]. Fig. 1 shows a schematic of a typical UTLT. The figure demonstrates that there are remarkable differences between UTLTs and common road tunnels. First, UTLTs typically consist of a main looped tunnel and multiple branch tunnels, which indicates that a UTLT is not a sole tunnel but a complex tunnel system. Second, UTLTs could link several underground facilities, such as underground parks or underground commercial districts. The characteristics of UTLT structures significantly complicate the design of their ventilation. Furthermore, the complex structure of a UTLT and the high density of vehicles could increase the possibility of fire accidents and exacerbate the difficulty of exerting fire smoke control. Numerous studies have been performed to optimize normal operational ventilation and emergency ventilation (i.e., fire smoke control) for conventional road tunnels [2–4]. In these previous studies, longitudinal and transverse ventilation (or semi-transverse ventilation) have been identified as the two most prevalent ventilation strategies. These two strategies have also been proven effective in smoke control for conventional tunnels [5–8]. Gao et al. [9] also proposed the use of hybrid ventilation for control of fire-induced smoke in an underground facility.

The principle of exerting smoke control using longitudinal ventilation involves discharging smoke through a predetermined route downstream of the fire and preventing the smoke from spreading upstream. Thus, the critical velocity, as the minimum air velocity required to prevent smoke from spreading against the longitudinal ventilation flow, is particularly important in the longitudinal ventilation mode [2,10,11]. Wu and Bakar [2] proposed a set of

* Corresponding author. Tel.: +86 23 65120771; fax: +86 23 65120773.
E-mail address: yangdong@cqu.edu.cn (D. Yang).

http://dx.doi.org/10.1016/j.applthermaleng.2015.11.062
1359-4311/



(a) The plan view of a typical UTLT

(b) The network diagram of the typical UTLT

Fig. 1. Schematic of a typical UTLT.

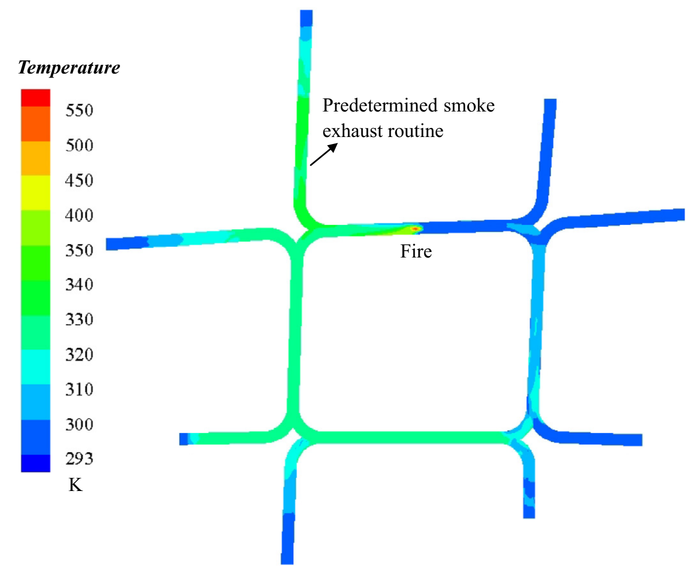


Fig. 2. Temperature distribution in a UTLT with an improper longitudinal smoke control system (a simulation case). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

dimensionless formulae of critical velocity based on small-scale experiments, in which the effects of tunnel geometry and fire plume distribution were considered. The correlation between the ratio of longitudinal ventilation velocity to critical velocity and the back-layering length was obtained as well [10]. Yang et al. [11] investigated the influence of fire geometry and combustion process on critical velocity. They concluded that previous models of critical velocity based on the preservation of Froude number failed to involve the effect of fire geometry and combustion process. Because of the advantages with respect to cost and simplicity of installation, the longitudinal ventilation mode has been widely employed in conventional tunnels. Relevant Chinese codes suggest that longitudinal ventilation of a long tunnel should be subdivided if the length of the tunnel exceeds 5000 m [12]. Currently, several UTLTs employ the longitudinal ventilation strategy for smoke control because the branch tunnels of the existing UTLTs are relatively short [1,13]. It is notable that both the design and operation of longitudinal ventilation in a UTLT are considerably more complex than those in conventional tunnels. Because UTLTs are composed of multiple branches and usually exist as a looped system, if the longitudinal smoke control strategy is employed, it is essential to determine an appropriate route for smoke discharge and to guarantee that smoke does not infiltrate other tunnel branches. Otherwise, the smoke will occupy multiple tunnel branches and even the whole UTLT, as shown in Fig. 2. This reasoning suggests that the critical velocity should be guaranteed to prevent smoke back-layering in the fire branch; moreover, an appropriate airflow velocity should be generated to prevent smoke from infiltrating the branches that are used for pedestrian evacuation, especially for the tunnel branches that are downstream of the fire and adjacent to the smoke discharge route. Only limited research has been dedicated to the smoke control of a looped UTLT. Hua et al. [14] conducted a series of numerical simulations to determine the optimal smoke control strategy for a UTLT. Jiang et al. [15] suggested the use of a fireproof rolling shutter to prevent smoke propagation in UTLTs. A hybrid field-network simulation approach was proposed to study the airflow pattern of a longitudinally ventilated UTLT to avoid the high computational cost associated with a fully three-dimensional numerical simulation [16]. Wang et al. [17] employed fire dynamics simulator to test the effectiveness of some smoke control strategies for a UTLT based on performance-based design. Despite of the studies, efforts are necessary for establishing more general methods for the smoke control of UTLTs with looped structures and determining the key engineering parameters. Du et al. [18] proposed a methodology for dividing the characteristic sub-regions of a longitudinally ventilated UTLT. A design method is proposed to simultaneously realize both the critical velocity in the fire branch and the air velocity for preventing smoke infiltration to the adjacent tunnel branches downstream of the fire. However, the effectiveness of the design parameters proposed in Ref. 18 has not been verified by experiments. Furthermore, in a UTLT, effective longitudinal smoke control could be actualized through different operational modes of jet fan systems, which has not been previously investigated in depth.

Transverse (or semi-transverse) ventilation can also be used to exert smoke control in a UTLT. In a transverse (or semi-transverse) ventilation mode, hot and toxic smoke is confined to the region near the fire source and is exhausted through nearby smoke vents [19]. Therefore, the area of the smoke-contaminated region could be considerably smaller than that in a tunnel with longitudinal ventilation. For a UTLT with several tunnel branches, the apparent