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Experimental Research on the Smoke Control System in a Complex Road Tunnel Fire

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Abstract

Twelve full scale experiments are carried out to research the effectiveness of smoke control system designs in a complex road tunnel in the event of a fire. The segment of the tunnel used for the experimental program is equipped with mechanical exhaust ducts and mechanical air supply ducts along the tunnel. In the experiment program, two sizes of fires are included, having heat release rates of 1.5 and 3.8 MW. A variety of smoke control strategies are included in the program in order to compare smoke movement behavior and the relative effectiveness of the smoke control strategies. The experiments demonstrated that the spread of the smoke can be contained effectively within two zones with an adjusted transverse smoke control system.

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Keywords: Road tunnel, Smoke control, Transverse ventilation, Back-layering.

Nomenclature

ΔH_c heat of combustion (kJ/kg);

$\dot{m}''$ burning rate of the fuel(kg/m^{2}s);

A area(m^2);

D pool diameter (m);

$\kappa\beta$ the radiative emission coefficient.

T interface temperature；

T_{amb} ambient temperature；

T_{max} the maximum temperature found on the centerline in the averaged results.

V_c critical velocity [m/sec (fpm)]

K Froude number factor

K_g grade factor

G acceleration caused by gravity [m/sec^2 (ft/sec^2)]

H height of duct or tunnel at the fire site [m (ft)]

Q_c heat fire is adding directly to air at the fire site [kW(Btu/sec)]

P average density of the approach (upstream) air [kg/m^3(lb/ft^3)]

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C_p specific heat of air [kJ/kg K (Btu/lbR)]

A_c area perpendicular to the flow [m^2 (ft^2)]

T_f average temperature of the fire site gases [K (° R)]

T_0 temperature of the approach air [K (° R)]

1. Introduction

The consequences of a fire in a tunnel can be significant given that a confined narrow space, with limited evacuation options for people, especially for fires in tunnels without fire protection system(s) [1]. Emergency ventilation systems are needed to control the flow of smoke and heated gas in order to provide a tenable environment for tunnel users and to assist emergency responders [2]. The common ventilation approaches in tunnels are longitudinal and transverse ventilation systems. Appreciable research has been conducted to investigate the longitudinal ventilation system in short one-way tunnels [3]. Usually a critical ventilation velocity is required to preventing the occur of back layering[4]. Air curtain is another option to control the movement of smoke, the effect of the air curtain on smoke control has been studied by Ingason and Haukur and Ying Zhen [5].

Complex road tunnels usually have more than two portals and have many sub-tunnels or garages collected with them as indicated in Table1. In some case the tunnels complete a full "loop". In tunnels with multiple portals, smoke movement is much more complicated than the one way tunnel, with the potential for smoke to spread to sub-tunnels and garages. As such, the longitudinal smoke ventilation system is not appropriate for use in complex road tunnels without considering the connection with other sub-tunnels or garages. Little research has been conducted to describe smoke movement in the complex road tunnels.

Table.1. Complex road tunnels built within 5 years in China

Name of the tunnel	Length of the tunnel	Number of sub-tunnels
Beijing Financial complex tunnel	Main tunnel 1600m，sub-tunnel 600m	4
Beijing Olympic Park complex tunnel	Main tunnel 5500m，sub-tunnel 1970m	25
Beijing Tongzhou District complex tunnel	Main tunnel 1500m，sub-tunnel 1450m	8
Beijing Aonan complex tunnel	Main tunnel 1720m，sub-tunnel 1090m	4
Chongqing Jiefangbei complex tunnel	Main tunnel 2800m，sub-tunnel 1705m	11
Chengdu Dayu complex tunnel	Main tunnel 2800m，sub-tunnel 2765m	8
Zhengzhou Dongxin District tunnel	Main tunnel 2918m，sub-tunnel 8082m	15

Therefore, a new adjusted transverse emergency ventilation system is proposed as a means of confining smoke to specified smoke zones. In contrast to full balanced transverse ventilation[6], the adjusted transverse ventilation duct vents are mounted to supply fresh air and exhaust smoke at specific locations based on the location of fire source, the tunnel grade, and direction of traffic flow. A variety of airflow velocities may be used in those scenarios. Full scale experiments are conducted to investigate the effectiveness of the transverse ventilation strategies for controlling smoke produced by fires in the experimental section of main tunnels.

The direction of traffic flow goes either up or down. Drivers travelling downstream of the fire are free to escape by means of their own cars, whereas drivers travelling upstream need to evacuate by walking. If the direction of traffic flow goes upward, the direction of the smoke movement and the occupant evacuation is opposite, it is good for occupants to evacuate. On the contrary, if the direction of traffic flow goes down, the smoke probably will pose threat to the occupants in the upstream of the fire. Therefore, the design of smoke management in tunnels should take the direction of traffic flow and the grade of the tunnel into account.

2. Experimental setup

2.1 Tunnel description and ventilation system

Field experiments are carried out in a real complex road tunnel, depicted in Fig 1. The main tunnel is a completed oval with a length of 2.8 km. Several sub-tunnels and garages are connected to the main tunnel. The yellow part of the main tunnel indicated in Fig. 1（K1+200 to K1+680）are used as the experimental section. All tunnels used in this project are