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Experimental study on smoke temperature distribution under different power conditions in utility tunnel

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ABSTRACT

The longitudinal and cross-sectional temperature distributions are measured in reduced-scale tunnel fire experiments with different fire power conditions. Field tests are carried out in a utility tunnel with pool fires. The experiments studied the ceiling temperature along the tunnel centerline, the vertical temperature below the ceiling and the temperature in the direction of radian in the same section with the fire source. The results from the burning experiments are analyzed. The longitudinal temperature distribution along the tunnel can be fairly well fitted by exponential equations. And the thermal radiation of the smoke layer has a significant effect on the temperature below the ceiling. In addition, in the direction of tunnel radian, the temperature growth rate of the region above 45° are obviously faster and the temperature is higher. Therefore, to shorten the response time of the detector to the fire, it is desirable to place the heat and smoke detectors at the top of the utility tunnel.

1. Introduction

With the rapid development of urbanization, utility tunnels have been constructed in more and more countries and regions, such as China, France, Japan, the United Kingdom, Germany, Spain, New Zealand, and Australia. According to preliminary statistics, there are now 69 cities in China to build utility tunnel with a total length of about 1000 km [1]. The utility tunnel systems contain mainly communication and electric power cables arranged in groups. Although the cable insulation and jacketing materials are treated with flame-retardant, short-circuit, broken circuit and welding may still cause a fire [2]. In case of a fire, the high temperature generated by the combustion will ignite the adjacent combustible materials, and the toxic exhaust gas generated by the combustion will spread quickly in the tunnel, which increases the difficulty of fire rescue directly and destroys the tunnel structure. In addition, the small space, high combustibles density, complex tunnel environment have increased the difficulty of fire extinguishing for the firemen. Therefore, in order to minimize structural damages and losses of human lives, it is necessary to study the spreading mechanism of fire smoke and distribution characteristics of temperature in utility tunnel.

Recently, investigators mainly adopted the experimental tests and numerical simulation to investigate the behaviors of fire-induced smoke flow and temperature in utility tunnel fire. Li [3] obtained the heat release rate and the mass loss rate parameters of the PVC cable materials by the thermo gravimetric analyzer and the cone calorimeter. On this basis, the FDS numerical simulation software was used to study the smoke spread process and temperature changes in utility tunnel. Kim et al. [2] studied the effects of shape geometry on the fire-induced flow characteristics by numerical simulation methods, and put forward scientific suggestions on

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the installation position of heat and smoke detectors in the construction of utility tunnel. For the study of utility tunnel, many scholars at home and abroad mostly stay in the development process, internal fire protection design and the cost of construction, and there are a few literature on the utility tunnel fires. However, as a special cross-section tunnel, the temperature distribution in the utility tunnel fire is similar to that of the tunnel fire. Therefore, the research situation of the tunnel fire will be described next. Kurioka et al. [4] carried out experimental tests using 1/10, 1/2, and full scale model tunnels with rectangular and horseshoe cross-sections. An empirical formula for maximum temperature of smoke layer with distance was established based on the result of 1/10 scale model tunnel and verified by the results of 1/2 scale and full scale experiments. Chen [5] conducted a series of experimental tests using methanol pool fire in a 1/9 reduced-scale tunnel, and the temperature in the tunnel and the mass loss rate of the fuel were measured. The results demonstrated that the ceiling temperature inside the tunnel varies with the change of sealing ratio. Tian [6] carried out a group of full-scale tunnel fire experiments, and measured the temperature distributions in tunnel with different longitudinal ventilation conditions. On the basis of theoretical analysis, a temperature attenuation model of tunnel under the condition of stable fire smoke layer was established, and the upper limit temperature attenuation curve of fire source was obtained. Ji [7] established a tunnel model with adjustable width, and the influences of tunnel width on mass loss rate and temperature distributions were investigated. The results show that the tunnel width has little effect on the mass loss rate and the maximum smoke temperature under the ceiling. In numerical simulation, Modic, J. [8] analyzed the serious causes of a series of accidents in some tunnels. Air velocity, air temperature and wall temperature in the case of fire were studied under the condition of opening the emergency ventilation system using computer simulation software. Niu [9] built a rectangular tunnel model based on the data of a practical tunnel in Shanghai. Through numerical simulation, the spreading process of flue gas and the variation of temperature at different time were studied, and provided some reference for fire emergency rescue. Zhong [10] revealed the generation mechanism of smoke bifurcation flow though analyzing the effect of longitudinal ventilation velocity on smoke flow field, temperature distribution within smoke layer and height of smoke layer. K. Brahim [11] used a small-scale tunnel model to study the effects of two ventilation systems on temperature distribution and validated the results. The above researches mainly analyze the characteristics of temperature distribution of common tunnels such as rectangular and horseshoe cross-sections. However, as a special cross-section tunnel, the temperature distribution of the fire smoke inside the utility tunnel is only studied by a few scholars, and mainly used numerical simulation.

In this paper, three fires with different power have been conducted in a midscale utility tunnel. The study involves multiple diesel pool fire in a test gallery, with the temperature of horizontal direction and vertical direction measurements at many locations in the tunnel, and the characteristics of temperature distribution in the special cross-section tunnel are analyzed.

2. Experimental setup: 1/3.6 scale tunnel

2.1. Tunnel description

According to Table 7.1.1 of Technical code for urban utility tunnel engineering (GB50838-2015), the fire risk of power cable compartment and water tank are Class C and Class D, respectively [12]. Compared with the water tank, the power cable compartment is more dangerous. Therefore, the present paper focus on/ aim at exploring the smoke flow and the temperature distribution in a cable fire.

The reduced-scale tunnel is used with scaling ratio of 1/3.6 to the full-scale tunnel and the shape of the reduced-scale tunnel matched that of the full-scale tunnel. A series of experimental tests were carried out in a 1/3.6 reduced-scale tunnel, which is composed of three parts, the power cable compartment, the emergency evacuation channel and the water tank. The reduced-scale tunnel is circular and horizontal, 1.8 m outer diameter and 1.5 m inner diameter. The schematic side cross-section of the tunnels is shown in Fig. 1 [13]. It is 10 m long, with a quarter circle cross section around 1.77 m^2 in the power cable compartment surface. At the same height as the power cable compartment, there are safe walkway for safe evacuation of the staff connected by a fire door. In

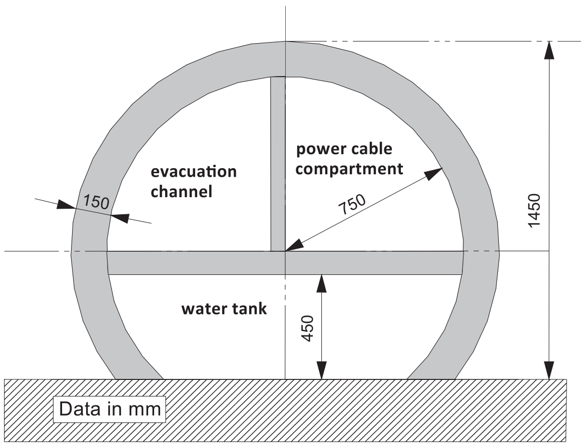

Fig. 1. Cross-sectional view of the tunnel.