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Numerical study on water curtain system for fire evacuation in a long and narrow tunnel under construction

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ABSTRACT

Numerical simulations are carried out to study the water curtain systems for fire evacuation in a long and narrow water tunnel under construction by shield tunnelling machine (STM). The designed fire is located near the working face with a heat release rate of 40 MW. In numerical simulations, the grid resolution is analyzed. The temperature, soot density, species concentration and visibility at different cross sections with different water curtain conditions are studied. The water curtain can partially prevent the smoke from spreading outside, and cool the smoke outside evidently for a better evacuation. It can appreciably decrease the carbon dioxide concentration and increase the oxygen concentration outside the water curtain. However, the water curtain will largely increase the soot density and decrease the visibility at the lower part of the water tunnel. The droplet from the water curtain will put impact on the flow and make a turbulent flow nearby.

1. Introduction

In recent years, many tunnels have been constructed in the underground space for the convenience of transportation around the world. During the construction process of a tunnel with shield tunnelling machine, the constructors in the tunnel stay in an enclosed condition, easy to be weary and depressive. The ventilation of the tunnel generally depends on the fresh air blown in by a fan installed at the entrance of the tunnel through a ventilation duct. When a fire breaks out in this enclosed place, a large amount of smoke is generated with high temperature resulting in difficulty for evacuation and damage to the concrete linings of the tunnel. Therefore, it is very important to study the fire growth, smoke propagation and emergency evacuation for a tunnel under construction.

Water mist system has been widely used as a fire protection tool. Many researchers and engineers have carried out both experimental and numerical studies on the effect of water mist system on fire protection.

1.1. Experimental study on water mist system

Large-scale or small-scale experiments have been carried out to investigate the performance of the water mist system recently. Ingason (2008) carried out a model scale experimental study on the effect of water spray systems on the fire in a longitudinal tunnel. A wood crib was used to simulate the fire source. The parameters varied were the water flow rate and water pressure, the longitudinal ventilation rate and the arrangement of the nozzle system. Yu et al. (2009) carried out a small scale compartment experiment to study the restraining efficiency and related factors of the ultra-fine water mist on the coal combustion in the goaf of a coal mine. It showed that the water mist could effectively reduce the heat release rate of coal, increase the concentration of O_2 and CO, and decrease the concentration of CO_2. Chen et al. (2009) carried out small-scale experiments to study the water mist fire suppression under different longitudinal ventilation velocities in tunnels. Three stages of the fire suppression process were found. The factors which influenced the efficiency were investigated. The coupling system of water mist and ventilation system was recommended. Ying and Ingason (2013) carried out 28 model scale tests to study the performance of an automatic sprinkler system in a longitudinal ventilated tunnel fire. The results showed that high ventilation rates and low water flow rates resulted in a failure of the automatic sprinkler system. Xu et al. (2016) carried out an experimental study on the suppression performance of a charged water mist on gas explosion, with a small charged water mist generator and a gas explosion simulation device. Experimental results indicated that the gas explosion could be more efficiently suppressed by the positively charged water mist. Zhang et al. (2016) conducted a series of water mist fire suppression tests. The

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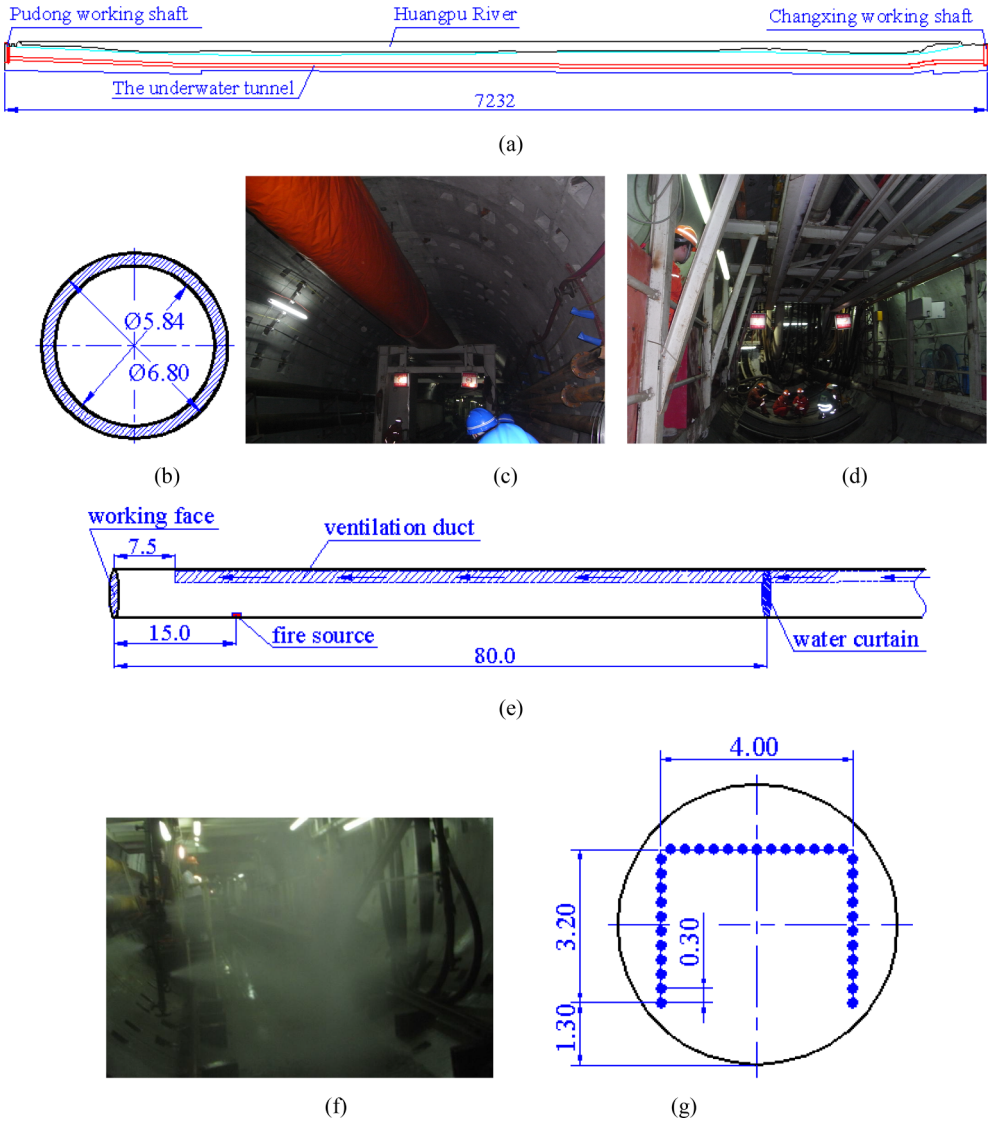

Fig. 1. Diagram and photos of the tunnel and the water curtain. (a) Longitudinal section of the tunnel, (b) Cross section of the tunnel, (c) Photo of the outside of the STM, (d) Photo of the inside of the STM, (e) Layout of the tunnel near the STM, (f) The water curtain is working, (g) The layout of the water curtain.

ethanol pan fire was used in the tests. The parametric analysis was done on the water mist nozzle. The test results showed that the 70 bar and K = 1 water mist successfully suppressed the fire in the test. The radiant heat flux attenuation and the fuel surface cooling effect were the key fire and flashover suppression mechanisms. Xu et al. (2017) made an experimental investigation of the influence of obstacle and ultrafine water mist on the mitigation of methane/coal dust-mixture explosion. The experimental results showed that the maximum explosion pressure, explosion temperature, and increase rate of pressure decreased by employing the ultrafine water mist. Chang et al. (2017) conducted two full scale tunnel fire experiments using heptane pool fire. The performance of the spray system was studied. The results showed that the spray system could effectively lower the temperature and the heat flux for providing a relatively safe environment for both the evacuees and the tunnel. Li et al. (2017) built a lab-scale experimental dust collector system to study the influence of water mist on the dust filtration performance. The filtration performance was evaluated and the morphology of dust deposition on the filter was analyzed. Moderate water mist was found to be beneficial, but an excess water mist was able to decrease the filtration performance. Zhou et al. (2018) conducted a series of full scale pool fire suppression experiments to study the fire extinguishment performance of water mist system. The continuous and cycling discharge modes were tested. With the comparison of the characteristic parameters, such as the smoke temperature, radiative and total heat flux, fire extinguishing time, and carbon monoxide and oxygen concentration, it concluded that the application of cycling discharge mode substantially improved the fire suppression efficiency. Shrigondekar et al. (2018) studied a simplex water mist nozzle and its performance in extinguishing liquid pool fire. The full cone simplex nozzle with an orifice diameter of 1.2 mm was used to produce water mist. Different characteristics such as the discharge coefficient, spray cone angle and mass flux density were measured. Extinction performance of the nozzle was compared with the performances of other water mist systems. It indicated that their simplex nozzle was much better in extinction performance than other simplex nozzles reported in the literature. Wang et al. (2018) carried out a lab-scale experiment to study the effect of a water mist curtain on the control of fire smoke in a channel. Fatal factors for occupant evacuation in a fire, such as carbon