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A novel evacuation passageway formed by a breathing air supply zone combined with upward ventilation ☆

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HIGHLIGHTS

- BTES can be used to create a safe, smoke-free evacuation passageway out of the tunnel.
- BTES is optimized in this study.
- The influence of HRR, fire source location and detection time are discussed.

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ABSTRACT

With the development of transportation, the tunnel has become one of the important facilities of railway, highway and subway transportation. However, fire hazards occurring inside the tunnel may incur huge numbers of casualties and property losses. In this paper, a breathing air supply zone combined with an upward ventilation assisted tunnel evacuation system (BTES) is introduced. It can be used to create a safe, smoke-free evacuation passageway out of the tunnel. The BTES is optimized to achieve high-performance. The impacts of heat release rates, fire source locations and fire detection times are also discussed.

The carbon monoxide (CO) concentrations found when utilizing the BTES were significantly lower than that found when utilizing the traditional ventilation system. An obvious, clean evacuation passageway was created by the BTES. The maximum CO concentrations in the BTES evacuation passageway were below 10 PPM throughout the entire combustion process. A larger CO concentration gradient in the vertical direction was detected with the BTES than that found in other ventilation systems. This finding means that the lower part of the tunnel has a lower CO concentration with the BTES, which benefits the evacuation process. The impacts of fire source locations and fire detection times were tested to ensure the system reliability, and it was found that the performance of the BTES was not sensitive to them.

1. Introduction

With the development of transportation, the tunnel has become one of the important facilities of railway, highway and subway transportation [1]. However, fire hazards occurring inside the tunnel may incur huge numbers of casualties and property losses, such as those in Burnley, Austria in 2007 [2], Frejus, France/Italy in 2005, Dague, Korea in 2003 [3] and

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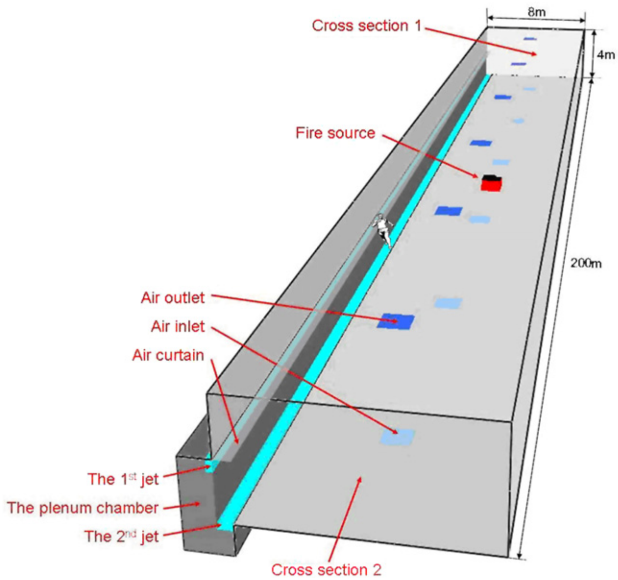

Fig. 1. The geometry of the tunnel.

Gotthard, Switzerland in 2001 [4]. Hundreds of people were killed in those tunnel fires. Statistics have shown that smoke is the most fatal factor in fires, and about 85% of the people were killed by fire induced smoke [5]. In a tunnel fire, or other underground fires, more toxic carbon monoxide will be produced because of incomplete combustion due to the lack of oxygen. Additionally, because the tunnel is a narrow and enclosed space, the smoke infiltration can be very fast [6], making timely evacuation of the people even more difficult to accomplish [7–9].

To facilitate the evacuation of people during fires, five types of commonly used ventilation systems have been developed for usage in tunnels [10]. They are the longitudinal ventilation system, supply air semi-transverse ventilation system, exhaust air semi-transverse ventilation system, full transverse ventilation system and the natural ventilation system [11,12]. The primary objective of these ventilation systems is to reduce the smoke concentration in the tunnel. However, they actually reduce the average smoke concentration of the entire tunnel, rather than that of the lower part of the tunnel, used for human evacuation. As a result, the smoke concentration in the lower part of the tunnel is still at a very high level when utilizing the traditional ventilation systems [13,14].

As a matter of fact, it is not necessary to ensure that the entire tunnel space is clean, nor is it even necessary to ensure that the entire lower part of the tunnel space is clean [15]. It is only necessary to ensure that a safe, smoke-free evacuation path is clean [16–18]. Based on this, both breathing air supply zone ventilation and upward ventilation can be introduced into the tunnel ventilation system design. These two ventilation methods are types of personal ventilation. Personal ventilation is one of the three main building ventilation methods, along with mixing ventilation and displacement ventilation. Personal ventilation supplies clean air directly to the breathing zone, and has been proven to be more effective than mixing ventilation or displacement ventilation [19,20]. All of the traditional tunnel ventilation systems mentioned above can be categorized into either mixing or displacement type building ventilation methods. None of these traditional tunnel ventilation systems mentioned above can be categorized as a personal type of building ventilation method.

In this paper, a breathing air supply zone that was combined with an upward ventilation assisted tunnel evacuation system (BTES) is introduced. The BTES can be used to create a safe, smoke-free evacuation passageway out of the tunnel, bringing a new perspective to ventilation system design and human evacuation systems for usage during tunnel fires. The BTES is optimized in this study, and the influence of the heat release rate, the fire source location and the fire detection time are also discussed.

2. Study object

The tunnel chosen for this study is a typical rectangular tunnel, as shown in Fig. 1. The size of this tunnel is 200 m × 8 m × 4 m. The BTES is installed along one side of this tunnel. When it is in operation, people can evacuate through the evacuation passageway created by the BTES.

The BTES includes four sections: the plenum chamber, the air curtain, the 1st jet and the 2nd jet, as seen in Fig. 2. The plenum chamber is installed at the corner of the tunnel connected with the 1st jet and the 2nd jet. The width of both jet is 0.5 m. The 1st jet is installed in the side wall of the tunnel, at a height of 1.5 m from the tunnel floor, and it is used to ensure a clean breathing zone. The two jets form the breathing air supply zone when combined with upward ventilation. In addition, the installed height of air curtain is 2 m.