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# A study of fire smoke spreading and control in emergency rescue stations of extra-long railway tunnels

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A B S T R A C T

An emergency rescue station providing a link across the two neighboring tubes in an extra-long railway tunnel is an integral part of evacuation routes in the event of a train fire. Inhalation of toxic gases and hazardous smoke is a major cause of fire deaths. Therefore it is of key importance to reserve escape routes, in upstream of the fire source and cross passages, clear of the poisonous substances by supplying fresh air to the cross passages and the tunnel in which the train on fire draws up simultaneously. In this study, numerical simulations were carried out with the Fire Dynamics Simulator, given parameters of a real tunnel, to determine the optimal air flow. The influence of air flow on the spread of gases and smoke and the distribution of temperature was also investigated. Analysis of the results show that a sufficient air flow along the tubes may effectively limit the thickness of the smoke layer, thus leaving adequate risk-free space above the ground for the emergency evacuation. An air flow in excess of the optimum, however, results in significant non-uniformly distributions of the smoke layer over the evacuation paths, which causes an increase in risk. Further, pressurized air supply in the cross passages proves beneficial to the reduction in the air temperature and in the dimensions of certain regions, whereas it exerts an insignificant effect on the thermal radiation of the fire source. Accordingly fire suppression systems, e.g., curtain producing sprinklers, are expected in emergency rescue stations.



## 1. Introduction

Driven by the advances in tunnel engineering and the growing demand for public transport, extra-long railway tunnels appear increasingly common. The increased length of extra-long tunnels poses new challenges to fire safety. When trains catch fire in the semi-closed structure of extra-long tunnels, poison gas and heat are more likely to accumulate within the long and narrow space in a short period of time, which will greatly hinder the escape and fire rescue work. A large number of experiments (Teruo, 1977; Toshio, 1975; PIARC, 1999; Xu et al., 2004) have demonstrated that a train on fire can travel safely in tunnel for 15 min in speed of 80 km/h, and the maximum safe distance is 20 km (Chow, 1996). Chinese railway tunnel construction regulations proclaim that emergency rescue stations shall be realized in tunnels or tunnel groups which exceed 20 km.

Previous researches primarily focus on case studies of train fire that occurs in railway tunnels and rescue stations. Normally in these studies, it is believed that numerical simulation is capable of mimicking actual fire characteristics to a certain extent (Bari and Naser, 2005; Li et al., 2014; Sung and Hong, 2006). Numerical simulation methods of computational fluid dynamics (CFD), such as Fluent and Fire Dynamics Simulator (FDS), have been widely used to determine the fire characteristics (Mcgrattan and Hamins, 2010; Woodbum and Britter, 1996). These results show that there exists good consistency between the experiment-based tests and numerical simulations. In addition, Shen et al. and Wang investigated characteristics of smoke spreading and temperature distribution by using FDS and Fluent respectively (Bai, 2014; Shen, 2013). Under different conditions of ventilation modes and parameters, the results prove that the two methods lead to briefly the same conclusions.

By studying the related research, we realize that few studies concern smoke spreading and smoke control in emergency rescue station or each component of the station. In this work, therefore, we used the fire dynamics analysis software FDS to construct the numerical analysis model, which was combined with a practical

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case of tunnel project. The numerical models are based on large eddy simulation, one of the important research methods in fluid mechanics, and the fire scale was set to be invariable. In addition, in order for safe and secure egress routes, comprehensive considerations should be taken in the accident area, which can hinder hot smoke from spreading into regions upstream of the fire source and exhaust smoke from entering the cross passages of the rescue station. Based on characteristics of smoke spreading and temperature distribution in the tunnel, we obtained the best longitudinal velocity in the accident tunnel and ventilation velocity in the cross passages, which is key to the successful evacuation of passengers in case of fire.

## 2. An overview of the tunnel project

The tunnel in question is a double-track single tunnel, the left and the right tubes measure 22.175 km and 21.834 km in length respectively, and the maximum buried depth of the tunnel is approximately 900 m. In order to enhance the function of disaster prevention, an emergency rescue station of 550 m has been set 11 km away from the entrance of the tunnel. While, the cross passages, which can connect the two one-way tunnels, have been placed every 50 m, there are 11 cross passages in total. In Fig. 1, a train runs in the left tunnel in direction from A1 to A2, when the train catches fire and stops in the rescue station, passengers could immediately escape through the nearest cross passage from the accident tunnel to the safe tunnel. In this case, the region upstream of the fire source (the upstream region, for short) refers to the area from the fire source towards A1 direction, and in the other direction, the area is called the region downstream of the fire source (the downstream region, for short). To ensure the safety of the evacuation, longitudinal velocity in the accident tunnel ($V_l$, for short hereafter) and pressurized air supply rate in the cross passages ($R_{pas}$, for short hereafter) should be given in order to inhibit the smoke from spreading into the cross passages, and present the flue gas from spreading to the upstream regions respectively. In addition, the rescue stations are equipped with ventilation systems, power systems, signal systems, washing fog spray systems to meet the need of disaster protection.

## 3. Model construction and condition

### 3.1. Model construction

A 1:1 scale model of the tunnel is designed, and 600 m is selected as the length of tunnel model for calculation efficiency (Li et al., 2010). In the simulation model, the length of the rescue station is set as 500 m for convenience, 11 cross passages have been set along the length of rescue station at intervals of 50 m. The size of train for numerical simulation is in line with the actual size of the Chinese Electrical Multiple Unit (EMU), known as "Hexie Hao", which consists of 16 carriages, and the size of the carriage is 25.000 m * 3.380 m * 3.700 m (length * width * height). The mesh, regarding as the minimum compute unit, is divided with reference to a series of comparison about grid size by the National Institute of Standards and Technology (Nist, 2012). In our model, the grid measures 0.5 m in height, 0.5 m in width and 1 m in length, while in the cross passages the length of the grid is decreased to 0.5 m. The grids within 30 m of simulated fire source are more densely arranged that each grid is of 0.25 m in each dimension.

### 3.2. Conditions

From the engineering practice angle, several problems concerning passenger train types, train running state, fire protection equipment, and flammable material are considered to determine the fire scale. In recent years, new type of passenger trains are generally used incombustible material or nonflammable material, fire fighting equipments and fire detection alarm system are equipped in the carriage, based on the analysis of fire dangerous scenario, the fire scale for calculation determined to be 20 MW (Richard et al., 2005). Based on the fire load density of the combustible and combustibility of decoration material, the fire belongs to $t^2$ super quick fire, and calculate the value of fire increasing modulus, it need 326 s to reach the heat release rate of 20 mw. In the simulation model, reasonable ventilation quantity in the cross passages are measured independently, which guarantees no smoke spreading into the cross passages. Longitudinal ventilation is widely used in tunnels (Barbato et al., 2014; Lee and Tsai, 2012; Weng et al., 2016). On top of that, the changes of temperature distribution and smoke spreading under different longitudinal velocity are studied in detail.

#### 3.2.1. Determination of fire scenario parameters

We suppose that the train can still travel to and stop right at the station properly in case of fire. According to the Chinese "Code of Rules for Railway Technical Management" and the restrictions for emergency braking distance of railway passenger train, the train catch fire at the entrance of the tunnel or before arriving at the rescue station, the recommended way of deceleration are "first drive at a regular speed and then with a braking deceleration" and "drive with a braking deceleration", with the duration of 216 s and 72 s respectively.

Piston wind is produced in the process of emergency braking,

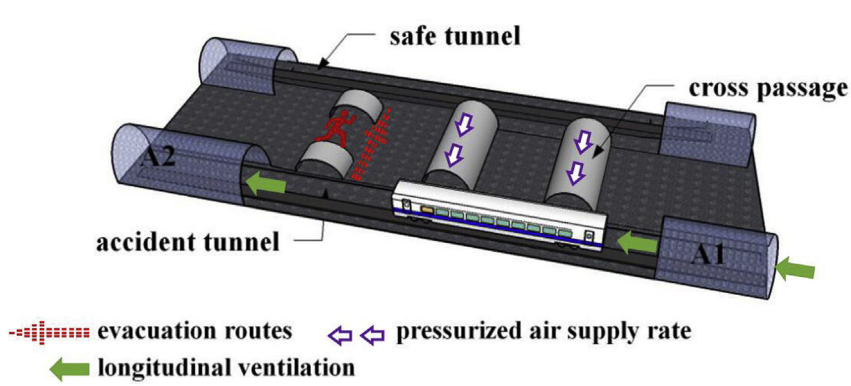


**Fig. 1.** Diagram of an emergency rescue station in the tunnel.