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The evacuation safety analysis of fire scenarios in the entire acoustic barriers of elevated Mass Rapid Transit System

Hue-Pei Chang [a], San-Ping Ho [b,*], Chao-Shi Chen [a], Tzu-Sheng Shen [c]

[a] *Department of Resources Engineering, National Cheng Kung University of Tainan, 70101, Taiwan, ROC*
[b] *Department of Occupational Safety and Health, Chang Jung Christian University of Tainan, 71101, Taiwan, ROC*
[c] *Department of Fire Science, Central Police University of Taoyuan, 33304, Taiwan, ROC*

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ABSTRACT

The entire acoustic barrier is similar to a tunnel for the elevated Mass Rapid Transit (MRT) System. Current smoke ventilation designs for the elevated MRT system have no precedent standards to follow, and therefore are all designed based on experience. For the entire acoustic barrier design in the MRT system in Taiwan, this research used FDS to simulate fires under the compartments with different heat release rates and varying number of compartments in varying lengths of entire acoustic barriers. The effects of the smoke layers produced by the fires on the evacuation of the personnel were observed. This research used a 1000 m entire acoustic barrier without smoke vent for discussion, and it was discovered that evacuation proved to be ineffective when the heat release rates were 10, 20, 30 and 40 MW. However, under circumstances where openings of different sizes were used at the top of the barriers, or changes were made to the heat release rates, or alterations were made to the number of passengers and compartments, a formula was developed in which all passengers could be evacuated under these varying circumstances; and this formula can be used as reference during the designing of natural ventilation vents in acoustic barriers for elevated MRT systems.

1. Introduction

Serious tunnel fires around the world have caused serious damage to life and property, such as the Tauern tunnel fire in Austria and the Mont Blanc tunnel fire, therefore most long tunnel researches used forced ventilation (Chen et al., 2013; Chen and Chuah, 2004; Hu et al., 2008b; Lee and Ryou, 2006; Li and Chow, 2003; Li et al., 2011) to discuss the relationship between the changes in smoke layers and evacuation (Mu et al., 2014; Přibyl and Přibyl, 2014). The scenarios which are less discussed are the natural ventilation systems used in shallow urban road tunnels due to costs and installation difficulties, especially the entire acoustic barriers used in elevated MRT systems. In a natural ventilation research, Harish and Venkatasubbaiah (2014) used numerical analysis to prove that the smoke venting performance of ceiling vents can be improved by varying the vent size and fire source locations. The ceiling openings are effective in transferring hot gases and reducing the longitudinal smoke velocity. Hu et al. (2014) also used Fire Dynamics Simulator (FDS) to study the temperature profiles of buoyancy-driven gas flow; they discovered that the gas temperature profiles along the ceiling were symmetrically similar for upstream and downstream with respect to ceiling extraction only; and for both upstream and downstream, they decay faster longitudinally with increasing ceiling mass extraction velocity; in actuality, using FDS to discuss experiment data and theoretical analysis for smoke, wind velocity, and location of fire source yielded consistent results (Chen et al., 2015; Hu et al., 2008a; Meng et al., 2014). Ura et al. (2014) used a 1/12 scale model tunnel of a shallow urban road tunnel and proved that the smoke spreading distance was constant and independent of heat release rate, and that the thickness of the smoke layers in the tunnel thinned out quickly due to the natural ventilation. Kashef et al. (2013) developed empirical equations based on the one-dimensional theory to predict ceiling temperature and smoke length under natural ventilation conditions; also, the temperature decay formula and referenced temperature formula could be used to express the smoke temperature. Yuan et al. (2013) conducted 1/15 reduced-scale experiments using the Froude number conservation to investigate smoke diffusion characteristics in tunnel fires with natural ventilation. Results showed that all factors with exception of the smoke curtain had no significant effect on the dimensionless ceiling temperatures in the fire section of the tunnel. Furthermore, fire sizes and train blockages had little effect

* Corresponding author.
E-mail address: spho@mail.cjcu.edu.tw (S.-P. Ho).

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Nomenclature

D^*	characteristic diameter	g	acceleration of gravity (m/s^2)
$\dot{Q}$	HRR (kW)	x	heat release rate (MW)
ρ_∞	air density (kg/m^3)	y	minimum design width of the exhaust vent (m)
c_ρ	specific heat of air (J/kg °C)	z	compartments of MRT
T_∞	ambient temperature (K)		

on the dimensionless ceiling temperatures in the non-fire section of the tunnel. Wang et al. (2009) conducted a full scale experiment with most of the smoke discharged directly out the tunnel through roof openings, showing favorability of exhausting smoke by roof openings. However, as temperatures of the smoke layers decrease, some of it might backflow and mix with the smoke-free layer below, resulting in lowering of visibility and showing disadvantage toward personnel evacuation. The documents above explain that both numerical simulations and experimental results show the effectiveness of natural ventilation in shallow urban road tunnels while being based on theoretical analysis. This research focuses on the tunnels made out of entire acoustic barriers for elevated MRT tracks near buildings; one of the main issues was if the passengers could all evacuate when the compartments were full, and therefore the size of the roof openings were critical toward the performance of smoke ventilation.

The MRT system shoulders the heavy responsibility of public transportation, and due to its difference to normal structures, the fire safety designs should consider its characteristics so as to ensure passenger safety. In Taiwan, in order to prevent noise from affecting the neighboring residents when the MRT passes through the city center, entire acoustic barriers are installed which completely surround the tracks, making the exterior look like a tunnel. The barriers are mainly made out of soundproof materials, metal plates and steel, therefore allowing openings to be made at the top of the barriers to be used as smoke exhaust vents.

The fire safety designs for the MRT system in Taiwan mainly follow NFPA 130 standards, and the fact that NFPA 130 (2010) has very few regulations on MRT overpasses is rarely discussed; also, there are no other design standards available for reference. The Taipei City Government Department of Rapid Transit Systems considered the scenario where a fire occurs when the train stops inside this shallow tunnel, which the smoke created could affect the evacuation of the passengers. 2 m wide openings were created at the ceiling of the barriers for smoke ventilation, and Fire Dynamic Simulator (FDS)+Evac (Korhonen and Hostikka, 2010) was used to evaluate if a four compartment train carrying 650 passengers could be safely evacuated under a 20 MW fire in a 200 m long entire acoustic barrier tunnel. Results were feasible when using this type of smoke ventilation system (S.T, 2012).

In Taiwan, the performance of ceiling smoke exhaust vents in acoustic barriers has not been thoroughly evaluated, therefore this research focused on the elevated MRT system in Taiwan and the design of entire acoustic barriers. The safety of passengers during evacuation in a fire was evaluated by varying the heat release rates of the fire, the width of the openings in the barriers, and the number of compartments on a single train.

2. Simulation methods

2.1. Simulation software introduction: FDS+Evac

This research used FDS+Evac simulation software as the research tool. FDS is a fire simulation software developed by the National Institute of Standards and Technology (NIST); its theory is to divide a space into a number of tiny grids while using the equations for conservation of mass, conservation of species, conservation of momentum and conservation of energy to calculate the temperature, pressure and concentration values of each grid in the fire scene. The results calculated by FDS can be presented by 2D or 3D animations (McGrattan et al., 2004, 2010, 2013).

2.2. Parameters of the FDS+Evac

This research collected the design data of entire acoustic barriers for the MRT system in Taiwan, including material, structure, form, size etc. as shown in Fig. 1 (MRT rail with 6 m high × 9 m wide entire acoustic barrier) , and also the data for the MRT trains. The data was used in FDS+Evac to evaluate if the passengers were able to evacuate using the overpass central escape walkway during a fire when the MRT train was parked inside the barriers. This research discussed the effect of opening sizes in the ceiling of the entire tunnel against the lowering of the smoke layer; the point to where the smoke lowered along with the evacuation time of people was used as a basis, and it was discovered that alterations to the fire source location would have little effect on the results in these scenarios, and therefore this study did not conduct scenarios with fire source location as the variable. The conditions and parameters used in the simulations are shown as follows:

(1) *Simulated track and length of entire acoustic barrier:* This research set up entire acoustic barriers on tracks 1000 m and 1500 m long, and created openings in the entire center portions of the ceilings to act as smoke exhaust vents (As shown in Fig. 2). The widths of the smoke exhaust vents were 0 m (no opening), 0.4 m, 0.8 m, 1.2 m, 1.6 m, 2 m, 2.4 m and 2.8 m. Fig. 1 is an FDS build model of a 200 m long entire acoustic barrier.

(2) *MRT compartments and passengers:* Four compartment train, total 68.4 m long, placed stationary in the center of the barrier. The compartments were linked together, with each compartment providing three exits on each side for passenger evacuation, and each exit being 2 m high and 1.6 m wide. The number of passengers inside the compartment was 650 people, which is the maximum capacity regulated by the Taipei City Government Department of Rapid Transit Systems, and all of them were evenly distributed in the compartment. Additionally, a train of six compartments containing 975 people and eight compartments containing 1300 people were included into the simulations for comparison. The movement speed of the passengers during evacuation was set at Adult movement speed inside FDS+Evac, which is 1.25 ± 0.3 m/s.

(3) *Fire source design:* The simulation scenario this research used was a fire under the compartment, with the fire source set in the center of the acoustic barrier, as shown in Fig. 1. SEDH (1997) showed the fire size of the Rapid Transit vehicle is 12 MW based on the combustible material of the vehicle. The setup was also based on assessment methods set by the Department of Rapid Transit Systems, Taipei City Government, which was a fast growing fire with HRR of 20 MW. And more fire load could be carried with the people