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Longitudinal ventilation for smoke control in a tilted tunnel by scale modeling

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ABSTRACT

Longitudinal ventilation systems are commonly installed in new tunnels in large cities of the Far East including Mainland China, Hong Kong and Taiwan. Many tunnels are found in big cities and some of them are inclined at an angle to the horizontal. However, smoke movement in tilted tunnels is not fully understood. In some of the tunnels, the ventilation system was designed based on presumed smoke movement pattern without experimental demonstration. Smoke movement pattern in a tilted tunnel model was studied by using a scaled model. A 1/50 tunnel model of length 2 m with adjustable angle to the horizontal was constructed by transparent acrylic plastics. A small 0.097 kW propanol pool fire was used as the heat source combined with burning pellets generating smoke. A fan placed at the upstream end was used to create longitudinal ventilation. Different ventilation rates were set using a transformer to control or adjust the fan speed. Experiments were performed with the tunnel angle varying up to 30° to the horizontal. Effect of smoke screens was also studied. The observed smoke movement patterns indicated that the shape of the buoyant plume inside the tunnel depends on the tilted angle. Smoke would flow along the tunnel floor due to gravity. The bending angle of the plume depends on the tunnel angle. Tunnel inclined at greater angles to the horizontal would give larger amount of smoke flow. Smoke movement pattern for a tilted tunnel with smoke screens was observed to be very different from some design projects. All results will be reported in this paper.

1. Introduction

Economics in the Far East is developing rapidly, particularly in Mainland China, Hong Kong and Taiwan. Large railway systems are constructed above ground and underground. Vehicular tunnels have been or will be constructed (Tam, 1998; Highways Department, 2008) for the highway systems in hilly areas. Passenger density is observed to be high (Chow and Yu, 2000) and fire safety strategy should be worked out carefully. Note that heavy goods vehicles (HGV) in vehicular tunnels may give problems because they carry combustibles. Traffic loading that of such HGVs in some vehicular tunnels was observed to be quite high with high Average Density Traffic. For tunnels linking to container piers in Hong Kong, over half of the vehicles are HGVs. The heat release rate may be high if an accidental fire in a HGV should occur. The possible heat release rates in burning HGV could be up to 200 MW as measured (Chow, 2007). Consequently, fire temperature measured in tunnel fires with burning HGV would be up to 1365 °C, instead of 250 °C used in tunnel design (Chow et al., 2008; Ingason and Lönnermark, 2005).

Smoke control systems are specified in updated fire codes in many countries (Fire Services Department, 2005; Ho et al., 2008). As there are train vehicles carrying large amount of combustibles in railway tunnels and HGVs in vehicular tunnels, longitudinal ventilation systems (Chow, 1998) are commonly installed in advanced cities such as Hong Kong. Operating jet fan installed at the side wall will drive air from one end of the tunnel towards the fire source. The tunnel is kept free from smoke downstream the fire (ASHRAE, 1995; Thomas, 1985). People trapped inside the tunnel would walk toward upstream direction of inflowing air. This is suitable for tunnels with a small cross-sectional area where transverse ventilation is difficult to install and demonstrated to work in Hong Kong (Apple Daily, 2007; Ho et al., 2008). However, the heat release rate of the fire would be increased to double the design values such as 5 MW due to the high supply rate of fresh air. A higher value of critical air speed is then resulted due to the higher heat release rate as reported earlier with computational fluid dynamics (CFD) (Chow, 2007; Hwang and Edwards, 2005).

Some tunnels are inclined at an angle to the horizontal. Smoke movement in those tilted tunnels is not fully understood. As a result, longitudinal ventilation in some tunnels (Ip and Luo, 2005) was designed based on presumed concept without clear demonstration by experimental studies. This approach was even applied to passenger tunnels (Hwang and Edwards, 2005) built in linking up underground spaces.

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Although there had been studies in the literature (Zukoski, 1995) including those on the trench effects (Drysdale et al., 1992) after the King's Cross fires in UK, the fire hazards are quite different for tunnels in the Far East. Both the vehicle combustible contents and occupant loadings are of very high values. Trucks were used to be overloaded because people are not so well educated. Drivers, willingly or unwillingly, carry more goods than the upper allowed safety limits, such as 10 tonnes of medium sized trucks. Further, social awareness on fire safety is rather poor in those areas. Therefore, risk is judged to be much higher as demonstrated by having so many big fires, including the one at a television tower in Beijing (Reuters, 2009). There are works on studying smoke movement in a tilted tunnel including those CFD simulations (Hwang and Edwards, 2005; Oka and Atkinson, 1995; Wu et al., 2000; Tajadura et al., 2006). Examples are the more recent works (Tajadura et al., 2006) on a passenger corridor

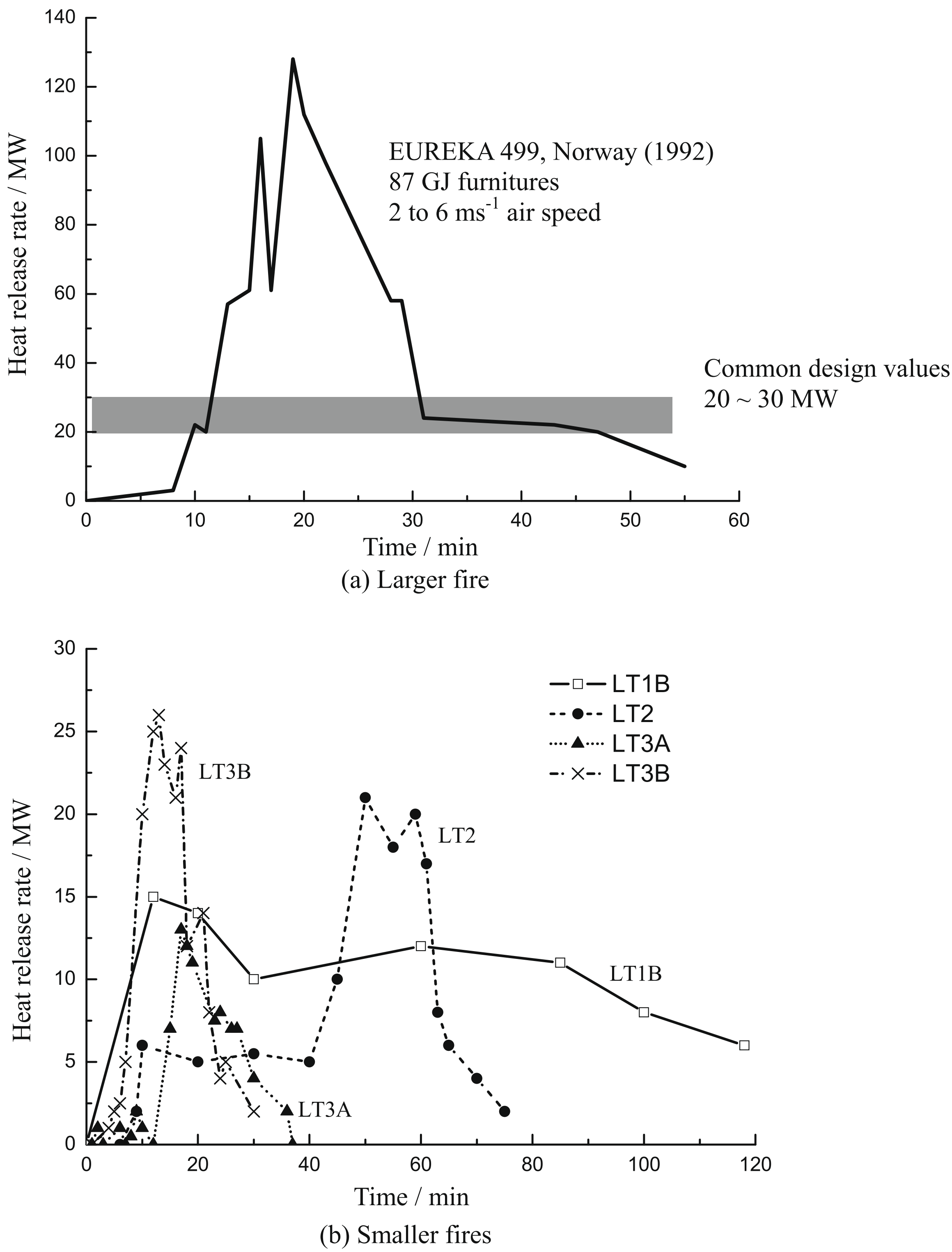

Fig. 1. EUREKA heat release rates curves reported by Ingason and Lönnermark (2005).