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 big cities of the Far East including Mainland China, Hong Kong and Taiwan. Many tunnels are found and some of them are inclined at an angle to the horizontal. However, smoke movement in those tilted tunnels is not fully understood. Some longitudinal ventilation was designed based on presumed smoke movement pattern without experimental demonstration.

Smoke movement pattern in a tilted tunnel model was studied by scale modeling technique. A 1/25 tunnel model of length 2 m with adjustable angle to the horizontal was constructed by transparent acrylic plastics. A small pool fire was put in with smoke generated by burning smoke pellets. Longitudinal ventilation was set up by a fan at one end. Different ventilation rates were adjusted by a transformer on controlling input to the fan motor. Experiments were performed with the tunnel angle varying up to 30° to the horizontal.

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 with higher angles to the horizontal would give larger amount of smoke flow. All results will be reported in this paper.

KEYWORDS
Smoke control, longitudinal ventilation, tunnel, scale model

INTRODUCTION
Economics in the Far East is developing rapidly, particularly in Mainland China, Hong Kong and Taiwan. Big railway systems are then constructed above ground and underground. Many tunnels (Chow 1998) are found and some of them are inclined at an angle to the horizontal. Similarly, long underground passenger tunnels are also constructed. Smoke control systems are specified in the new generation of fire codes in many countries. Longitudinal ventilation systems are commonly installed in modern tunnels in advanced cities such as Hong Kong. However, smoke movement in those tilted tunnels is not fully understood. As a result, longitudinal ventilation in some tunnels was designed based on presumed concept without clear demonstration by experimental studies. This approach might even be applied to passenger tunnels (Ip and Luo 2005).

Although there had been studies in the literature such as those by Zukoski (1995) in USA and on the trench effects (Drysdale 1992) after the King’s Cross fires in UK, the phenomena are quite different. Smoke movement in a tilted tunnel including those numerical simulations with Computational Fluid

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Dynamics was reported (Oka and Atkinson 1995, Atkinson and Wu 1996, Wu et al. 2000, Hwang and Edwards 2005, Tajadura et al. 2006). Examples are the more recent works (Tajadura et al. 2006) on a passenger corridor tilted with 2% along the upward slope. But those works were on simulating hot air induced by a heat source describing the fire.

Taking Hong Kong as an example, railway lines (Highways Department) are shown in Figure 1. Passenger loadings are observed to be very heavy and fire safety strategy should be worked out carefully. There are many tunnel sections which are tilted to the horizontal. Note that heavy goods vehicles (Chow 2007) in vehicular tunnels might give problems.

Smoke movement pattern in such tilted tunnel model should be studied carefully. In this paper, scale modeling technique (Quintiere 1988) was used. A 1/25 tunnel model with adjustable angle to the horizontal was constructed. The tunnel was of length 2 m and semi-circular cross-sectional area 0.0665 m$^2$. It was made of acrylic plastics so that smoke movement can be observed from outside. A small pool fire was put in with smoke generated by burning smoke pellets. Longitudinal ventilation design was achieved by driving air flow by a fan placed at one end. Different ventilation rates were adjusted by a transformer on controlling the fan motor. Experiments were performed with the tunnel angle varying up to 30° to the horizontal.

![Figure 1. Railway lines in Hong Kong](http://www.hyd.gov.hk/ENG/major/road/rail/index.htm)
THE MODEL

A 1/25 scale tunnel model of length 2 m was constructed of 4.5 mm thick transparent acrylic sheets. It has a semi-circular ceiling with cross-sectional area 0.0665 m² as shown in Figure 2. The height from the floor to the apex of the roof was 250 mm and the width at floor level was 300 mm.

An adjustment stand was used for varying the angle of the model tunnel inclined to the horizontal axis. A support was placed at three-quarters of the model tunnel length, and it was able to move vertically. The angle was adjusted by a protractor as shown in Figure 3.

Longitudinal ventilation was achieved by driving inlet air flow by a fan at one end. The fan holder was removed to avoid disturbing smoke observation. Different ventilation rates were adjusted by a transformer on controlling input to the fan motor.

Smoke movement patterns due to a pool fire in the model tilted at different angles were studied. Variation of smoke temperature was also measured.
SMOKE MOVEMENT PATTERN
Smoke patterns at various inclination angles with typical photographs at slopes of 5°, 15° and 25° are shown in Figure 4.

Smoke would flow toward the upward direction of the tunnel. Air was entrained horizontally from ambient. The buoyant jet would grow in thickness while moving up. As proposed by Zukoski (1995), heat transfer and skin friction at the wall and air entrainment from ambient would affect the development of the plume.

A smoke layer would form below the ceiling eventually. Initially, a clear zone was observed below the smoke layer. However, the space was filled up by smoke eventually to give a thicker smoke layer. Upward part of the sloped tunnel was filled up by smoke.

The above observation on smoke movement patterns suggests that the shape of the buoyant plume inside the tunnel depends on the tilted angle. The smoke plume would bend toward the tunnel surface at different angles. A bigger tilted angle would give larger flow in the tunnel. The plume bending angle is related to the tunnel inclination angle.

Transient values of the smoke temperature measured are shown in Figure 5.
DISCUSSION

As reported in the literature (Ip and Luo 2005) on a design case, the shape of smoke movement pattern is shown in Figure 6. This is quite different from those reported (Zukoski 1995) as in Figure 7; and in this study. Such smoke patterns would affect the fire safety provisions required. The design should be supported by experimental studies at least through a scale model as in the above study. Otherwise, the installed fire safety systems might not work as expected in case of fire.
CONCLUSION
From the observed smoke movement patterns, the shape of the buoyant plume inside the tunnel depends on the tilted angle. The smoke plume would be tilted along the tunnel floor due to gravity. The bending angle depends on the tunnel angle. A bigger tilted angle would give larger amount of smoke flowing in the tunnel.

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REFERENCES