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OBSERVATION OF SMOKE MOVEMENT PATTERN IN A SCALE TUNNEL MODEL WITH LONGITUDINAL VENTILATION

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ABSTRACT

Smoke control by operating the longitudinal ventilation systems was studied by scale models. The tunnel model was of length 2 m and of semi-circular cross-sectional area 0.0665 m^2. This model is 1/25 the size of a real tunnel. It was made of acrylic plastics so that smoke movement can be observed from outside. A small propanol pool fire of 0.097 kW was placed inside as the heat source with burning pellets to generate smoke. Longitudinal ventilation design was studied by driving air by a fan placed at one end. Different ventilation rates were set by using a transformer to control the power input to the fan motor. Smoke movement pattern in a tunnel fire was recorded.

1. INTRODUCTION

In the recent past long railways and vehicular tunnels have been constructed in Mainland China, Hong Kong and Taiwan, as a crucial part in the development of highway systems in hilly areas. Similar projects and developments are still continuing today and are likely to occur in the future. [1,2]. In such transport systems, the passenger density is generally observed to be high and fire safety strategy should be worked out with care and foresight. In particular, attention should be paid to heavy goods vehicles (HGV) in vehicular tunnels as they may cause many problems. The heat release rates in burning HGV have been measured to be 200 MW at maximum [3,4]. Therefore, the fire temperature estimated in some tunnel fires burning HGV would be up to 1365^{o}C, far exceeding the heat-withstanding limit of 250^{o}C used in standard tunnel design [1,5,6].

Longitudinal ventilation systems are now a commonly specified installation requirement [7,8] in many developing cities with crowded buildings and dense population. In a fire occurrence, big jet fans installed on side walls would drive air towards the fire source and propel the smoke to one end. The other opposite end of the tunnel would be kept free from smoke [9,10]. The people inside would then be able to proceed in upwind directions by walking against the air movement. The system is particularly suitable for tunnels with a small cross-sectional area where transverse ventilation is difficult to install, and has been demonstrated to be effective on many occasions including the 2007 tunnel fire incident in Hong Kong [11].

Before determining the key design parameters, smoke movement patterns in tunnels with longitudinal ventilation systems should be assessed and studied carefully, so as to obtain data in order to work out the appropriate air speed, the flow rates, fan pressure, fan power and operating scheme. As discussed, there are significant challenges on the application of fire models, particularly on Computational Fluid Dynamics, while applying performance-based design for fire safety provisions [12]. There have been more requests by the Authority to conduct full-scale burning tests in order to provide justification of design details. It is obvious that physical experiments would be exceedingly expensive, and repetitions in an effort to reproduce results could often not be attempted. Consequently, scale modeling studies are more widely used [13,14].

Scale modeling technique would be demonstrated as appropriate and effective [8,15-17] in this paper. A scale tunnel model of length 2 m and semi-circular cross-sectional area 0.0665 m^2 has been used in the experiments. It was created from acrylic plastics such that smoke movement may be observed from its exterior. A small propanol pool fire of 0.097 kW was placed inside as the heat source with burning pellets as smoke generators. The effect of operating longitudinal ventilation on smoke movement was the study objective. Air flow was provided by a fan placed at one end of the tunnel. Varying ventilation rates were achieved by using a transformer to control the input to the fan motor.

2. SCALE MODEL ON SMOKE MOVEMENT PATTERN

A scale model on smoke movement was studied as aforementioned [8]. A tunnel model of length 50 m with width 25 m and height 5.55 m with cross-sectional area 139 m^2 was considered as the original. A 1/25 scale model of length 2 m and cross sectional area 0.0665 m^2 was constructed with transparent acrylic plastics as material. The heat release rate was scaled down to 0.097 kW by preparing and burning propanol as the heat source. Pellets were put in the pool fire as generators of smoke.

Longitudinal ventilation was set up by a fan at one end. Differing ventilation rates were set using a transformer to control or adjust the fan speed. The effect of smoke screens was also studied.

Longitudinal ventilation in the scale model was provided by operating the fan as shown in Fig. 1. Effect of ventilation at speed of 0.5 ms^{-1} and 1.5 ms^{-1} were studied. The parameter in real tunnel smoke as heat release rate was calculated by Quintiere's scaling law [13,14].

3. RESULTS

The observed smoke movement pattern at ignition, initiation of combustion, the intermediate stage and final stage were recorded and shown in Fig. 2.

When the fan was not switched on and the longitudinal ventilation was not operating, smoke was observed to move to both sides of the tunnel. The entire tunnel was filled with smoke as evidenced in Fig. 2a. When the fan was operated at a low air flow speed of 0.5 ms^{-1}, smoke would extend to the two ends even with the air entrance as shown in Fig. 2b. This is a clear demonstration of 'back-layering' effect.

However when the fan operated at higher air flow speeds of 1 ms^{-1} and 1.5 ms^{-1} respectively, the smoke would be driven to the opposite tunnel end as shown in Fig. 2c and 2d. The other end was kept free of smoke.

4. CONCERNS OF LONGITUDINAL VENTILATION DESIGN

A higher critical air speed would be required to prevent back-layering as reported previously by CFD [5,18]. Operating the longitudinal ventilation system would increase the air supply rate to the fire source. The heat release rate of a ventilation-controlled fire, particularly one which involves a combusting HGV, would increase with a greater supply of fresh air.

The heat release rate of the fire can be estimated by the oxygen consumption method. As 1 mole of oxygen would be present in 4.76 moles of air, the oxygen concentration is proportional to the air intake rate. It has been estimated that burning 1 kg of air would yield about 3 MJ of heat based on mass balancing on complete reaction. As cited by Ingason and Lönnermark [4], the heat release rate would be raised by a factor of 4 for longitudinal air speed of 3 ms^{-1}, and by a factor of 10 for 10 ms^{-1}.

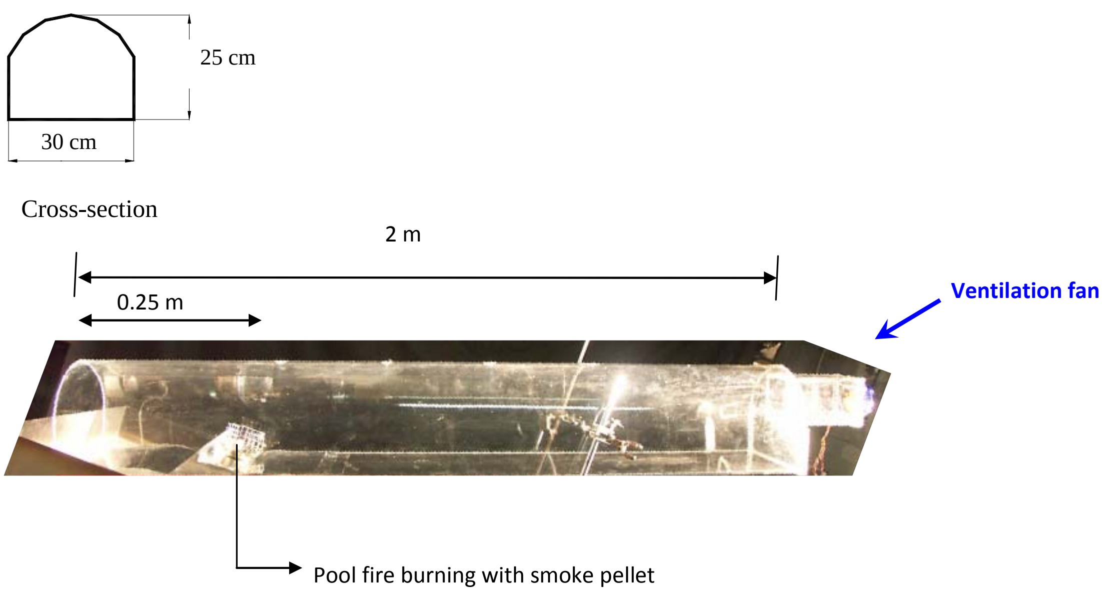

Fig. 1: The scale tunnel model

(i) Starting the fire

(ii) Intermediate stage

(iii) Final stage

(a) Fan not operating (b) Air speed of 0.5 ms^{-1} (c) Air speed of 1 ms^{-1} (d) Air speed of 1.5 ms^{-1}

Fig. 2: Typical smoke movements pattern

The heat release rate due to increased air supply should be considered as a crucial factor while designing a longitudinal ventilation system for vehicular tunnels. The critical air speed required to keep smoke out for upstream sides would increase as the heat release rate of the fire increases. All such work suggested that fire suppression systems should be considered as necessary installation in those vehicular tunnels. A combination of water mist and water curtain system [19,20] may be advisable.

5. CONCLUSION

Smoke movement patterns in a tunnel fire while longitudinal ventilation systems are in operation have been observed employing a scale model. The results would contribute towards the justification of CFD-predicted results in designing for tunnel fire safety. Scale models have been useful at the early stage of design. Once the actual design is more clearly determined, performance of full-scale burning tests on part of the tunnels would be advisable in order to confirm the design. Hot smoke tests would also be essential, at least in a tunnel segment, after completion of construction.

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