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Analysis of the Hsuehshan Tunnel Fire in Taiwan

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ABSTRACT

This paper focused on analyzing the Hsuehshan Tunnel Fire in Taiwan, which occurred from a bus fire in the afternoon of May 7, 2012 and caused two death and 34 injuries. Major object damages were reviewed and CCTV records were investigated toward understanding the fire temperature, smoke layers and situations of people in the tunnel refuge area (Fire Scenarios Analysis & Egress/Rescue Strategies of the 2012 Hsuehshan Tunnel Fire in Taiwan, MOTC, Taiwan, Jan., 2016.). Data collected from the fire scene were fed into fire scene reconstruction using CFD method (i.e., Fire Dynamics Simulators - FDS). It reveals that the fire temperature reached 800–900 °C and HRR was around 25–30 MW, which are consistent with the reviews of the incident and experiment data. Moreover, the fire temperature obtained from the CFD method when compared with experiment data is more reasonable. It is considered lift-threatening in terms of visibility, temperature and radiant heat flux for both road users and self-defense fire/rescue team when the fire heat reaches 10 MW. It was also reasoned that the fire spread through exit holes on the bus roof and heat was carried by the ventilation flow, leading to serious damage of lighting objects and cable traps above the bus. This study also suggests that the best option for people encounter tunnel fire is to leave their vehicles immediately and evacuate toward upstream direction of the fire. For those who are in the downstream of the fire, they should use the exit doors on the connection tunnel to escape the incident.

1. Introduction

The Hsuehshan Tunnel is ranked as the ninth long tunnel in the world (12.9 km, completed in 2006), which is constructed with two primary tunnels (two tubes one way) and one pilot tunnel. It suffered the first time of serious fire incident damage of 2 dead and 34 injured in 2012. Fig. 1 is the diagram of the tunnel that can help us to realize the tunnel structure clearly.

At 13:24, May 7, 2012, at 26 K Southbound in the Hsuehshan Tunnel, a small truck (Vehicle-F) had a flat tire. Two automobiles (Vehicle-D,E) and one bus (Vehicle-C) after it slowed down and dodged successfully. However, another bus (Vehicle-A) after them was suspected not keeping distance, and collided with the front wagon (Vehicle-B) and the bus (Vehicle-C). Then, the bus (Vehicle-A) and the wagon (Vehicle-B) were on fire immediately. The locations of these cars were indicated in Fig. 2. After detail incident investigation and review of CCTV in the tunnel, the main cause of incident is owing to bus (Vehicle-A) did not notice the front car and made the wagon (Vehicle-B) on fire by collision. There were totally 6 vehicles involved in the incident and caused 2 dead (passengers on the wagon (Vehicle-B)) and 34 injured (Incident Report of Taiwan Area, 2012).

2. Rescue routes

The Hsuehshan Tunnel Broadcast Center announced for the road users in southbound tube to pull their cars over on the waysides for rescue team to access easily and closed the northbound slip road to avoid other vehicles approach the incident when the accident was identified, indicated as Fig. 3. Meanwhile, the authority asked the police from different cities on both sides of the tunnel to operate traffic control. The Tunnel Broadcast Center announced right after the incident occurred and asked the road users to evacuate through the nearest connection tunnel from the contrary road. However, CCTV in the tunnel had observed that some road users not only refusing to obey the broadcast instructions for evacuation, but also staying right where they were, taking pictures and using phones at the incident site.

3. Temperature analysis

Many researches had completed full scale vehicle fire experiments

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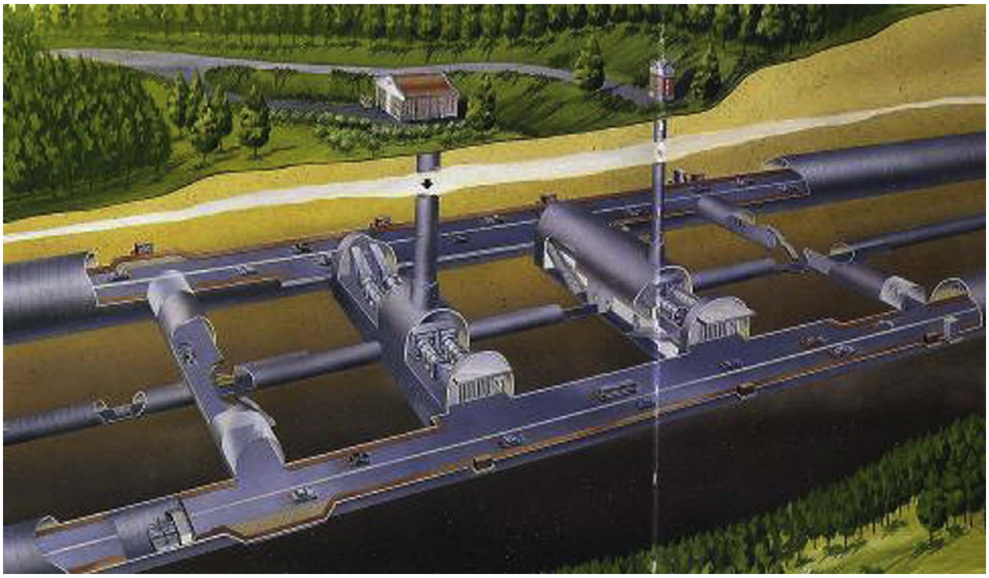

Fig. 1. Diagram of Hsuehshan Tunnel.

related to highway tunnels, and estimated fire heat release rate (HRR) and temperature in different scenarios.

3.1. The scale of tunnel fire

The burning period and heat released from the fire decided the combustion scale, which can be described as HRR and temperature. Table 1 shows various vehicle fire with estimated HRR level. For example, a bus fire is about 20–30 MW. An experiment of tunnel bus fire by EUREKA, Ingason and Lönnermark (2009) found that 800 °C is a significant value and proposed a temperature diagram as shown in Fig. 4. The maximum HRR of a bus fire measured in the experiment was 29 MW that happened in the time of 9th minute after fire ignition. Kunikane et al. (2002) also estimated the significant value of a bus fire as 20–25 MW HRR. The data is presented in Fig. 5.

3.2. Temperature in tunnel fire

There are two way to realize the temperature in a tunnel fire. One is based on experiment data, including incidents happened for the past years. The other is from data numerical analysis simulating (e.g., CFD method). It is difficult to directly obtain real temperature data from the real tunnel fire. Thus, the PIARC offered the maximum temperature in tunnel fire for different vehicle incidents as showed in Table 2.

3.3. Temperature in Hsuehshan Tunnel Fire

Detail investigation on the incident scene regarding the damages of aluminum lighting objects, copper cable trays, and steels of bus structure caused by the fire offered valuable information can help evaluate the temperature distributions of the Hsuehshan Tunnel Fire. Note that the melt points for aluminum, copper and steel are about 660 °C, 1083 °C and 1520 °C, respectively (National Fire Protection Association, 2011). Half of the bus (Vehicle-A), where collided with the wagon (Vehicle-B) suffered totally heat damage, and the situation became more and more serious as the area getting closer to the front side of the bus. The area where the bus (Vehicle-A) and the wagon (Vehicle-B) collided is the location with highest temperature estimate, and part of the lighting objects above this area get serious heat damage. According to PIARC's experiment value with the temperature of 700 °C and 20–25 MW HRR in one bus fire, these heat properties of bus and wagon collision fire should be modified as 25–30 MW HRR and burning temperature as 800–900 °C which are agreed with the reviews of the incident and experiment data.

The fire in the bus (Vehicle-A) spread through the exit holes on the bus roof. It led to the heat gas and flame to be carried out by the ventilation flow and caused serious damage of lighting objects and cable trays above the bus. The ventilation system of the tunnel, which is activated by the fire plume triggered the heat and smoke propagation more effectively. The fuel-rich flame in the bus (Vehicle-A) blew out from the roof exit holes resulting in entrainment air. It caused fire to spread forward downstream and burned down the cable trays and lighting objects, which were depicted in Figs. 6–9.

The burning temperature of bus is 800 °C, which is similar to the temperature in the simulation (800–900 °C) as described in Fig. 10. The propagation of heat and smoke also had been identified with the reviews of CCTV that makes the fire scenario more and more clear.

4. Smoke movement

Evacuation Stage: According to the design of Hsuehshan Tunnel ventilation system, it would be operated as the previous setting (2–4 m/s) after fire alarm system detects the fire and the situation would turn into the escaping model, indicated in Fig. 11, to keep the back-layer from the road users and to maintain a safety environment. 10 min after the fire ignition, CCTV monitored that smoke was controlled around the fire point and the visibility could be around 80 m at the upstream of fire point (as shown in Fig. 12), it means that the upstream road could be the choice of escaping route.

This study suggests that the best choice for people encountering a tunnel fire is to leave their vehicles as soon as possible and head to upstream direction far away from the fire. For those who are in the downstream of the fire, such as the passengers in the bus (Vehicle-C), they should use the exit doors on the connection tunnel to escape. In this case study, we observed that those who were in the downstream side of the fire did escape through the exit door, but they forgot to close