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Performance of a spray system in a full-scale tunnel fire test

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

[a] Department of Resources Engineering, National Cheng Kung University, No.1, University Road, Tainan City 70101, Taiwan, ROC
[b] Department of Occupational Safety and Health, Chang Jung Christian University, No.1, Changda Rd., Gueiren District, Tainan City 71101, Taiwan, ROC
[c] Department of Fire Science, Central Police University, No.56, Shujen Rd., Takang Vill., Kueishan District, Taoyuan City 33304, Taiwan, ROC

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ABSTRACT

In recent years, water spray systems have been accepted for protection of long tunnels in Taiwan. This research conducted two full scale tunnel fire experiments using 6 m^2 pool fire of heptane while data from one test is presented in this paper; the ceiling could reach 1022 °C under free burn. If a tunnel with spray nozzles operating at a pressure of 3.43 bar and a water flow rate of 360 lpm were installed every 5 m in a 50 m range for a 6 m^2 pool fire, not only could the temperature directly above the fire be lowered to below 500 °C within 30 s, the temperature of the other ceiling area would also be lowered below 300 °C and the heat flux would be lowered below 1 kW/m^2, therefore preventing subsequent fire spread. Moreover, the visibility of the fire returned to above 25 m after 150 s. This newly designed spray system can be installed on one side wall under simple maintenance without the need to shut down the tunnel, while the water can also spray to another wall to provide adequate wall cooling for tunnel protection. It can be effectively applied to rescue and protection in tunnels.

1. Introduction

Since the Hsuehshan highway tunnel in Taiwan was built in 2006, one serious fire incident occurred following its completion in 2012, which resulted in two fire fatalities. At present, a long tunnel of Shu-Hua highway is under construction and several other long tunnels are being designed. The fire safety in road tunnels has been of great concern in Taiwan. The fire protection designs for long tunnels in Taiwan mostly rely on ventilation systems to enhance rescue effort, and do not include water spray systems. Since tunnel fires tend to grow very rapidly and make rescue and evacuation very difficult, at the present, the Authorities Having Jurisdiction (AHJ) in Taiwan requires active fire suppression systems to be installed in the first of seven tunnels on Shu-Hua highway, called Dong-Aw Tunnel, which is 3.35 km long. Before a system is allowed for installation, its effectiveness in maintaining the tunnel environment for safe rescue effort needs to be demonstrated to AHJ. The aim is to evacuate personnel and activate the water spray system during the early stages of the fire, in order to achieve cooling and prevention of spreading of the fire, while also protecting the structure of the tunnel. This study is to investigate the performance of a spray system in a representative tunnel fire for practical application of the spray system in the Taiwan tunnels.

Recently, a significant amount of research on tunnel fires has been conducted. In 2003, five large-scale fire tests, including one pool fire and four heavy goods vehicle (HGV) trailer fires, were conducted in the Runehamar tunnel in Norway. (Lönnermark and Ingason, 2003) A peak heat release rate of 200 MW could be produced from a typical commodity found in HGV trailers. Further, the measured maximum gas was about 1350 °C. A maximum flame length up to 100 m ignited target fuel placed 70 m downstream at the floor. Simple and robust theoretical models have been developed to estimate and predict heat release rate, fire growth rate, gas temperature, flame length, radiation, flame spread, etc.

Quoted from the reports of tunnels in Brussels on the maximum temperatures in Eureka fire tests (EUREKA-Project EU499, 1995; PIARC, 1987, 1999), due to smaller cross-section areas with low air flow rates of 0.3 m/s and 0.5 m/s, the temperatures by burning cars and buses were 500 °C and 800 °C respectively. Fire tests also show that HGV (heavy goods vehicle) can cause up to 1000 °C of the ceiling and walls of the tunnel, while large tankers containing 50 cubic meters of gasoline can cause up to 1350 °C (Haack, 1998; ITA-AITES, 2003; KIVI, 1993). In fire tests of many well-known tunnels such as the Eureka fire (Ingason, 2003), the temperature gradient was very steep in the first 5 min to 10 min, and sometimes 15 min, when the fire grows rapidly, therefore making thermal and smoke removed very important.

Many tunnels are installed with longitudinal ventilation systems for venting of vehicle exhaust gases inside the tunnel. In the event of a fire, a longitudinal ventilation system is often brought into action to create a safe route upstream clear of smoke for evacuation and fire-fighting. The minimum air velocity required to suppress the smoke spreading against

* Corresponding author.
E-mail addresses: joanniech@gmail.com (H.-P. Chang), spho@mail.cjcu.edu.tw (S.-P. Ho), chencs@mail.ncku.edu.tw (C.-S. Chen), una179@mail.cpu.edu.tw (S.-W. Chien).

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Fig. 1. NFA tunnel is 80 m long, 10 m wide and 6.5 m high.

the longitudinal ventilation flow during tunnel fire situations is called "the critical velocity." Wu and Bakar (2000) carried out experiments in five models with the same height but different width to investigate the "critical velocity", which is affected by the fire size and tunnel geometry. The tunnel mean hydraulic diameter was used as the characteristic length in data analysis. It was shown that the experimental data for the five models can be correlated into simple formulae for scaling purpose, using the mean hydraulic diameter. Sun et al. (2016) discussed smoke blocking and the temperature cooling effect in the different water pressure, ventilation velocity, and nozzle arrangement in small scale tunnel tests.

However, the ventilation system will also feed the fire and cause it to grow. As the fire grows bigger without being brought under control, it will make the rescue effort very difficult and dangerous; also cause severe structure damage of the tunnel. In the last decade, the use of sprinkler systems in tunnels to stop further fire growth has been proposed. Li and Ingason (2013) studied the performance of an automatic sprinkler system in a model-scale tunnel with longitudinal ventilation. The results show high ventilation rates and low water flow rates resulted in failure of the sprinkler system. It was suggested that a sprinkler system could only be used in a tunnel with a low ventilation velocity or natural ventilation. It was also shown that the fire in their model study was suppressed efficiently after a deluge system was activated, if the flow rate was high enough.

Ingason et al. (2015) conducted the large scale tests that were carried out in the Runehamar tunnel, the main fire load consisted of 420 standardized wood pallets and a target consisting of a pile of 21 wood pallets. Fixed fire-fighting systems (FFFS) with 1.1 bar water pressure and K-360 (l/min/bar$^{1/2}$) at a nozzle yields a water flow rate of 375 L/min spraying from the center to two sides in the tunnel, while giving a coverage area of 37.5 m^2, which corresponds to water density of 10 mm/min. The nozzle was mounted every 5 m and sprays 375 L/min water horizontally in one direction. A total of six nozzles were used in the tests. The fire of 30 MW was controlled within 10–20 min and was suppressed within 10–30 min after the sprinkler was activated. The ceiling temperature decreased to below 400–800 °C.

NFPA 502 explains (NFPA502, 2011) that delay time for water system activation should not exceed 3 min. The designed amount of water or foam within the system should be able to satisfy at least 2 accident divisions. Central Nippon Expressway Company NEXCO recommends (NEXCO, 2012) that water spray system should discharge automatically; if it is a one-way tunnel the delay time for automatic activation should be 3 min; if it is a two-way tunnel the delay time should be 10 min. In reality, if the fire is not controlled before reaching 30 MW to allow fire rescue teams to intervene, then the expanded fire cannot be dealt with afterwards, therefore this research selected B-30 (6 m^2) fuel pan as the fire source with heptane as fuel. The tests performed in Norway (EUREKA-Project EU499, 1995; Haack, 1998; PIARC, 1999) paid special attention to smoke development and smoke dispersal from combustion of cars and trucks.

This research conducted two tests to prove the new spray system can provide sufficient cooling to protect the tunnel construction and to provide better evacuation and rescue conditions, while also preventing further spreading of the fire.

2. Experimental procedure

The newly constructed Dong-Aw tunnel in Taiwan has a cross-sectional area of 6.25 m in height and 11.5 m in car lane width, while being 3353 m in length. Two full-scale fire tests were conducted in a mocked-up tunnel at the Highway and Tunnel Accident Rescue Training Facility, National Fire Agency (NFA), Ministry of The Interior, in Taiwan, R.O.C. The NFA tunnel is 80 m long, 10 m wide and 6.5 m high. The cross-sectional geometry of the tunnel is similar to that of the Dong-Aw tunnel under construction. It allows two-lane vehicle traffic. Therefore, the test results of this study should be readily applicable to the Dong-Aw tunnel in the Shu-Hua highway. Fig. 1 is a photo of the mocked-up tunnel. No forced ventilation was provided during the test, since the operation of the Dong-Aw tunnel, where the tested spray system is to be installed, requires the shut-off of the ventilation system in the tunnel before activation of the spray system. Two sets of tests were conducted in total all yielding close results, and the results of only the first test was provided due to the similarities.

A new high-flow rate spray system was tested, using spray nozzles specifically designed for tunnel protection, as shown in Fig. 2. Gas

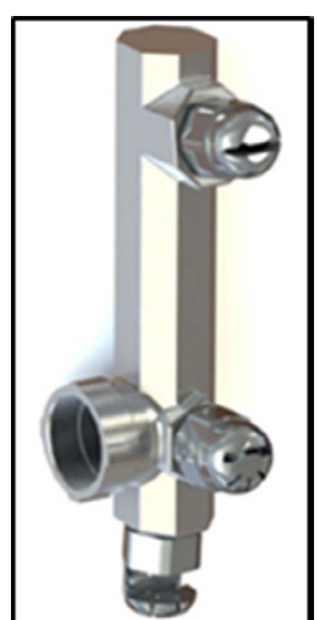

Fig. 2. Sidewall spray nozzle.