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Evaluation test of applicability of Compressed Air Foam fire extinguishing system in Subsea tunnel

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ABSTRACT

Recently, a mega project such as Korea-China or Kore-Japan undersea tunnel project has been emerged for detail discussion and the interest in undersea tunnel is on the rise. More severe damage by train fire is expected in undersea tunnel comparing to ground tunnel and thus the study on more efficient fire extinguishing system, besides existing disaster prevention design is underway. To that end, a full-scale fire tests using CAF fire extinguishing system which has been developed by modifying traditional foam fire extinguishing system for fire suppression at rescue station in timely manner were conducted over 7 times. The test was conducted after setting the rescue station in virtual tunnel with a car of KTX. As a result of spraying fire water and chemical mixed in compressed air foam directly to the fire source, 30 liter of Heptane combustibles was extinguished within 3 minutes. Applicability of compressed air foam to train fire at rescue station in undersea tunnel was has been proven and further study is considered required while changing the nozzle angle and location so as to achieve quick and easy extinguishing goal, making use of the advantage of CAF, as well as to reduce the fire water and chemicals required.

1. INTRODUCTION

Undersea tunnel linking Boryung-Taean (7 km-long) is under construction to open till 2018. Among the major foreign undersea tunnels which the Korean contractors have pushed ahead with are Euro Tunnel (France-UK, 0.45 km, opened in 1994), Hong Kong Tunnel (China, 9 km) and Bosphorous Tunnel (Turkey, 14.6 km) and the fire in

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Euro Tunnel (1996) Mont Blanc tunnel (1999) and Gotthard tunnel (2001) resulted in many investment and studies on tunnel life safety system, encouraging to develop and commercialize a non-spray fire suppression system in tunnel. While the vehicle is burning in tunnel fire, toxic gas and dark moke are generated in hot temperature, which could disrupt evacuation and fire-fighting activities. Moreover, the train covered with steel plate prevents fire extinguishing agent from penetrating into the fire source in fire situation and this study thus is intended to solve such problem with the solution to suppress the fire using foam fire extinguishing system directly to the train in fire.

2. Theory & principle of compressed air foam fire extinguishing system

Foam fire extinguishing system is designed to spray the large amount of fire water in a short time which is optimal to suppress the large scale fire, irrespective of indoor or outdoor fire. Furthermore, the chemicals used is harmless to humans and generates no toxic gas which is desirable for fire-fighting activities (Lee, Jang-won, 2012,2013).

Fire extinguishing agent used for foam fire extinguishing system is mixed with water in tank before being sprayed from the nozzle in a foam which covers the fire surface to create the air seal effect (Baik, Yeol-seon, 2005) (Fig. 1).

National Fire Safety Code (NFSC) of National Emergency Management; NFSC-10, stipulates the fire safety standards on installation, maintenance and safety management with regard to foam fire extinguishing system, saying that foam fire extinguishing system may be provided and used at the storage or factory where particular combustibles are stored or handled or hangar or 800 m2 or larger car parking lot. (National Emergency Management, 2012)

CAF system and major advantages are highlighted as below.

1) 1/7 of water spray system in fire pump capacity
2) 1/2 of existing system in main fire pipe diameter
3) Reduced drainage capacity
4) No power for fire pump is needed
5) Reduced capacity of fire water tank
6) Cost reduction by reduced work volume

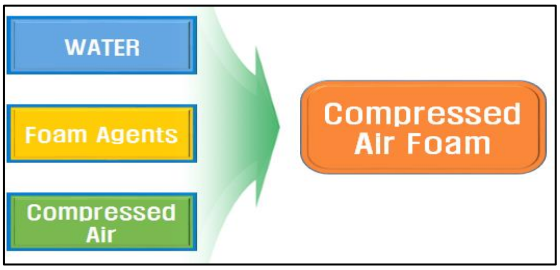


Fig. 1 Principle of CAF system

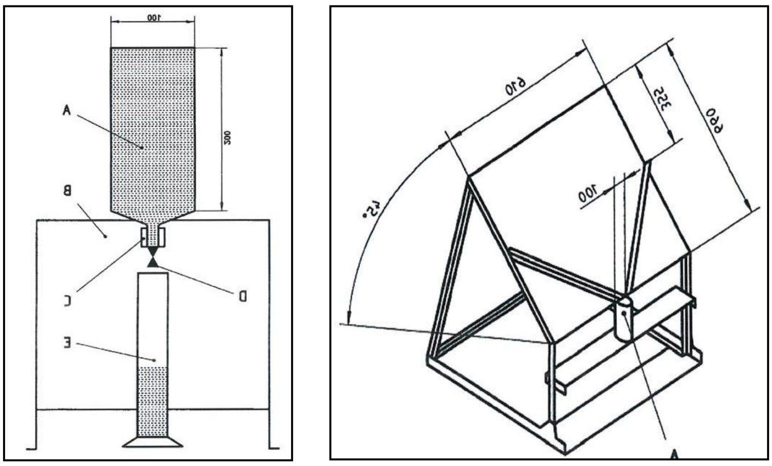
3. An experiment study on applicability of Compressed Air Foam fire extinguisher using Seawater

(1) Background and the Need

Undersea tunnel is designed to discharge the seawater by pump when the influent reaches to a certain level. This study is intended to use such effluent as fire water for compressed air foam fire extinguishing system in case of train fire so as to easily secure the fire water in undersea tunnel. To that end, foam reduction time was measured using foam collector in a bid to identify the performance variation of CAF fire extinguisher when using seawater as fire water, thereby verifying the applicability of seawater as fire water.

(2) Fabrication of foam collector and seawater-fresh water comparison test

This test was conducted in accordance ISO 7203 -1 (Specification for low expansion foam concentrates for top application to water-immiscible liquids) (Fig. 2). “Foam collector for measuring foaming rate and reduction time” was fabricated in accordance with the rule on foaming rate and reduction time and the test was conducted using CAF fire extinguisher. AFFF was 3% diluted to use as fire extinguishing agent and the tank was pressurized to 7 bar using nitrogen gas. Composite seawater was prepared for use in accordance with ISO 7203-1 (Fig. 3)



Components	%
Nacl	2.50
Mgcl2, 6H2O	1.10
Cacl2, 2H2O	0.16
Na2SO4	0.40
H2O	95.84

Fig. 2 Foam collector fabrication and composite seawater preparation method in accordance with ISO 7203-1

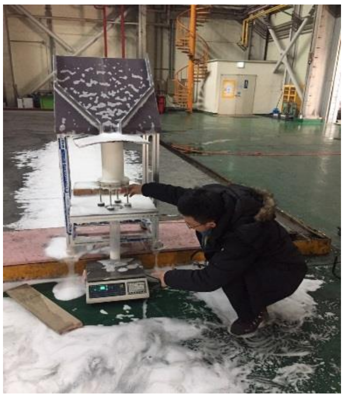


Fig. 3 Foam collector test and foam condition measurement

(3) Artificial brine comparison test

This test was conducted 19 times with fresh water and 15 times with seawater which totals 34 times. Reduction time was 237.73 seconds with fresh water and 215.60 seconds with seawater on average. Foaming rate was calculated by deducting the mass of empty foam container (kg) from the mass of full-loaded foam container (kg) in foam container volume (L) It’s 6.139 for fresh water and 6.270 for seawater on average. (Fig. 4)

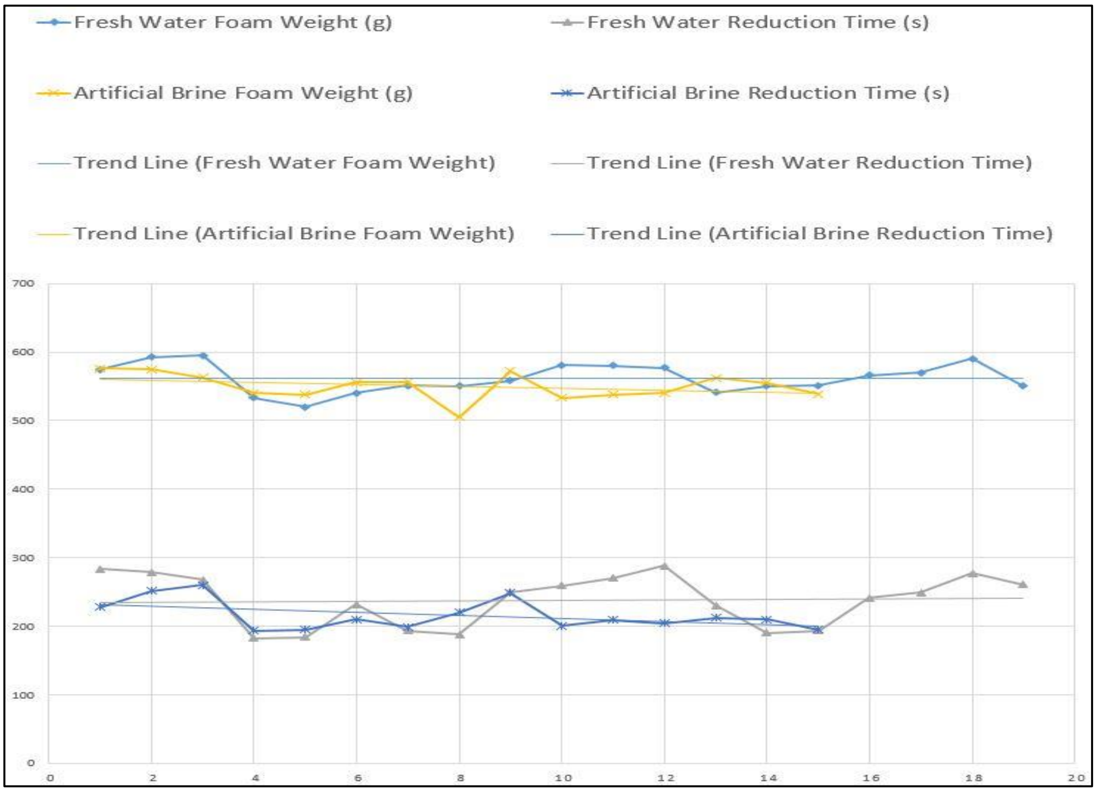


Fig. 4 Foam collector test and foam condition measurement

4. Full-scale fire test with compressed air foam

(1) Preparation for the test

Rescue station was set in virtual tunnel, a car was set as Fig 3 and 2 fire nozzles connected to compressed air foam mixer and fire pipe were arranged at each side, respectively, at 3m height downward (45°) at the 1st test and 1m height at the 2nd test. Injection pressure at the nozzle was set at 6 bar.

A car (3m wide x 4m deep x 2.5m high) of KTX train was fabricated with 5 m x 0.6 m glass window at 0.9m height vertically was set at both sides. A 0.9m x 1.5m door was set on front and rear, respectively.

Liquid heptane (10L) in steel container (1m x 1m) served the fire source. Time taken to be burnt up varied depending on environment but generally 2~3 minutes and heat release from a single source was 3.35 MW, two sources was 5.64 MW and three sources was measured as 11.88 MW

Aqueous Film-Forming Foam Agents (AFFF) which was used as undiluted foam liquid in the test was fluorosurfactant mixed with stabilizer which burns fast and forms moisturized bubbles and is fluidic and effective in initial fire extinguishing with a low surface tension, making it possible to apply to various types of fire (Lee, Seung-hoon, 2014) In this test, AFFF diluted to 3% was used as fire extinguishing agent and the tank was pressurized by nitrogen gas. (Fig. 5)

Fig. 5 CAF system arrangement

(2) Test

30 seconds after igniting the fire source, compressed air foam fire extinguishing system was activated manually and compressed air foam was sprayed from 4 nozzles. Preliminary test was conducted three times before this main test and the test from which the significant value was obtained was conducted 7 times in total. For first three tests, nozzle was set on top of the train while the nozzle was set at window height from the 4th to 7th test. (Fig. 6)

Temperature was measured by 5 thermocouples which were set on ceiling (2.5m height vertically grom fire source) at 50cm interval horizontally. Heat release rate was measured by Large Scale Con Calorimeter.

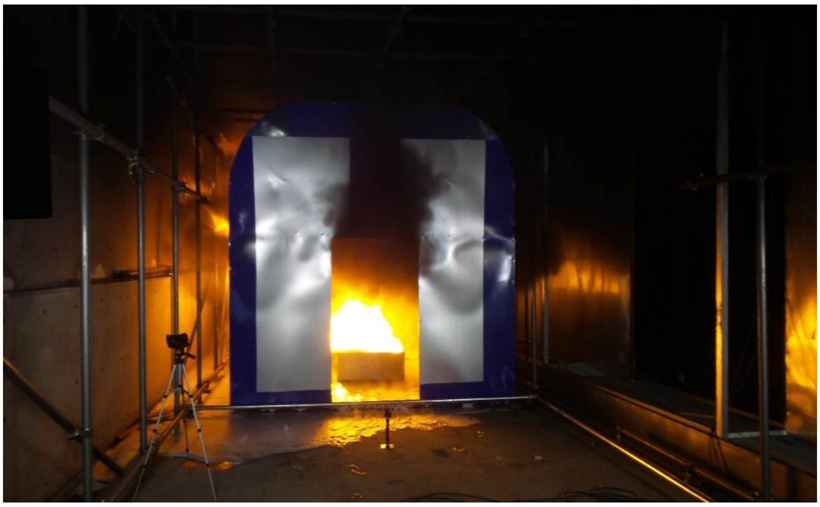


Fig. 6 CAF Discharging

(3) Result and Analysis

A full-scale fire test was conducted over 7 times and the test result is as Table 1. 3 tests were conducted first using fire water, fire water & undiluted foam liquid and CAF, respectively, and a single fire source was used. As seen in Table 2, they failed all to extinguish the fire but the time taken to extinguish the fire source in the 2nd and 3rd test was shortened from the 1st test thanks to heptane contained in steel container.

Table. 1 1st & 2nd test result

Parameter	1st test			2nd test			
	1	2	3	4	5	6	7
Nozzle height	train roof			train window			
burner	1			1	2	3	1
heat release rate (MW)	3.35			3.35	5.64	11.88	3.35
Fire extinguishing method	Water	water + Foam agents	CAF	CAF	CAF	CAF	water + Foam agents
Result	Failure	Failure	Failure	Success	Success	Success	Failure
Time to extinguishing (Second)	163	105	110	33	41	59	112

At the 3rd test when injecting compressed air to compressed air foam mixer, maximum temperature was lower than the 2nd test by about 100 ℃, indicating the cooling effect without using CAF directly to fire source, which was attributable to the effect of the part of compressed air from the nozzle on air current in train, causing to transfer some heat to the area where no thermocouple is set.

Table. 2 Temperature graph (1st test)

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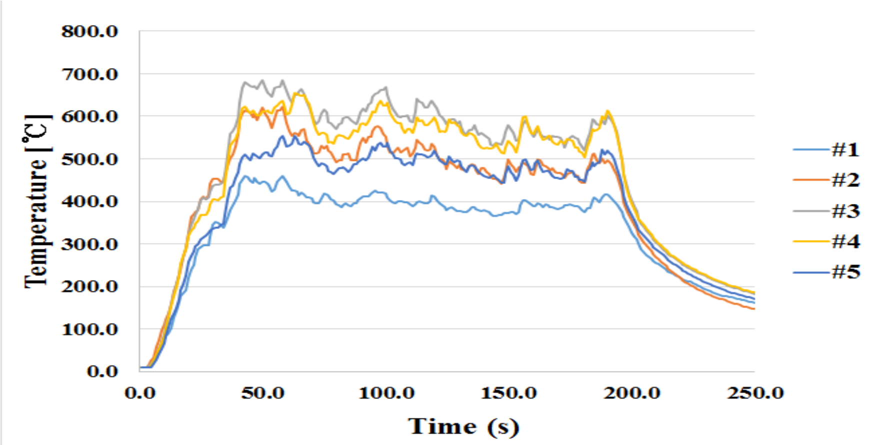
<tr><td>1</td><td>
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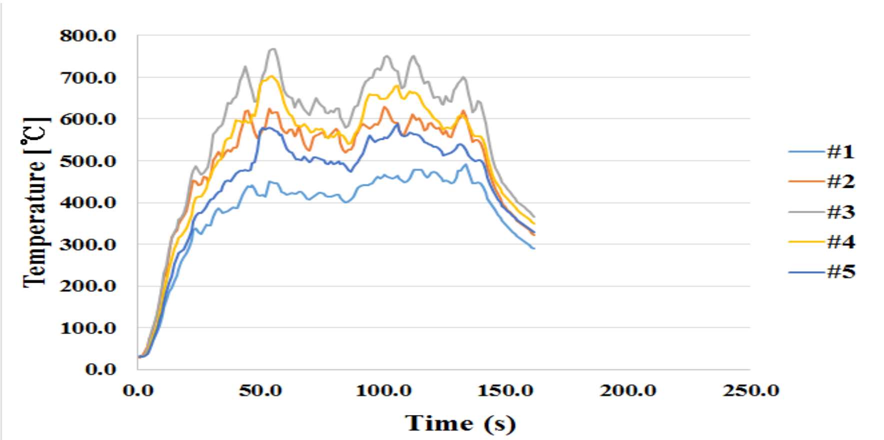
<tr><td>2</td><td>
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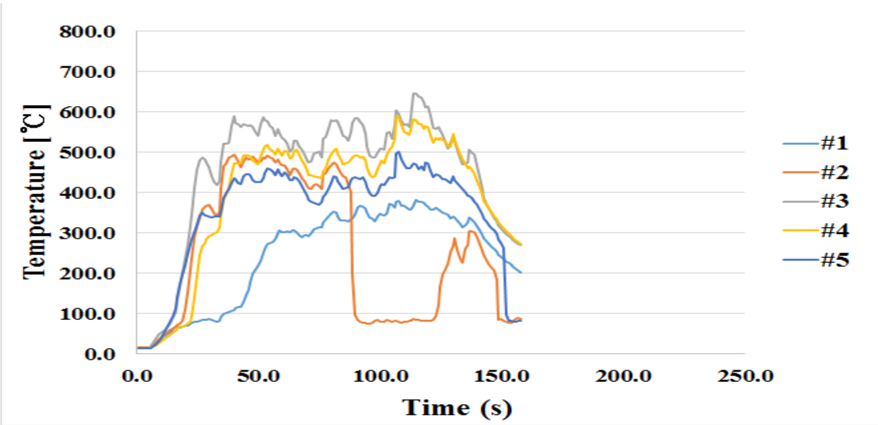
<tr><td>3</td><td>
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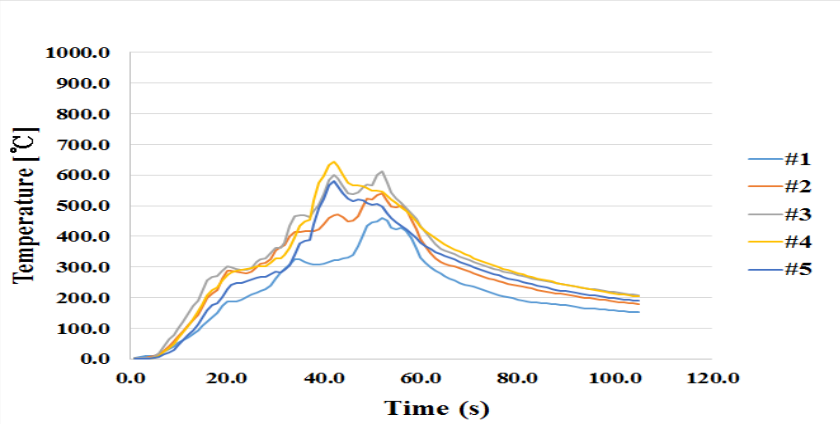
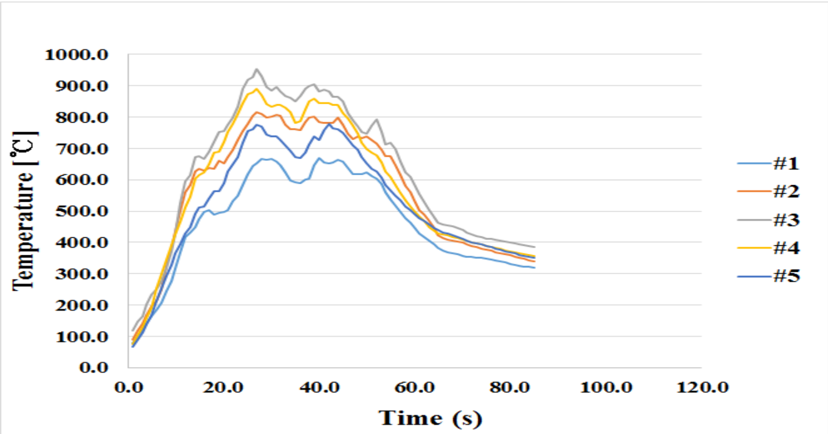
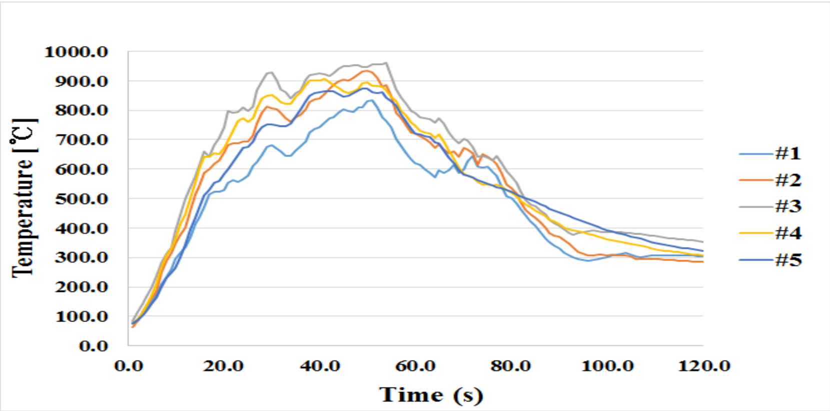
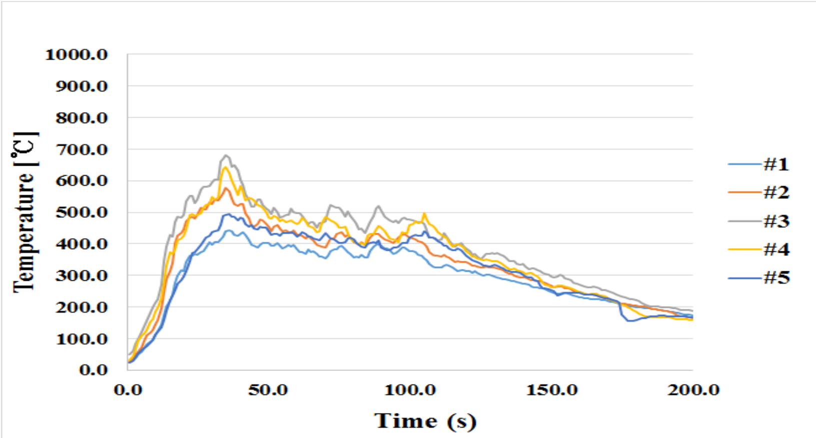
The second test was conducted three times using CAF while varying a fire source from a single to three. In case of a single fire source, temperature rose to 600 ~

700 ℃, which rose further to 900 ~ 1000 ℃, when a fire source was 2 or 3. As seen in Table 3, the fire was suppressed in 33, 41 and 59 seconds, respectively, and even a single fire source was not suppressed when using the fire water mixed with fire extinguishing agent.

Table. 3 Temperature graph (2nd test)

	2nd test
4	
5	
6	

7	

4. Conclusion

A full-scale fire test using compressed air foam in the scenario of train fire at rescue station was conducted to propose the fire extinguishing method in such situation and consequently, following conclusion was made.

1) Foam reduction time was measured using foam collector in a bid to identify the performance variation of CAF fire extinguisher when using seawater as fire water, thereby verifying the applicability of seawater as fire water.

2) The nozzle of compressed air foam fire extinguishing system shall be placed at the train window height so as to be directly involved in fire extinguishing activities.

3) Compressed air foam fire extinguishing system when installed at rescue station could suppress the fire with hear release rate 11.88 MW (heptane 30 L, secional area 3 m^2) within 60 seconds.

4) When using fire water mixed with fire extinguishing agent without compressed air, it could not suppress the fire with heat release rate 3.35 MW (heptane 10 L, sectional area 1 m^2)

Appropriateness of compressed air foam fire extinguishing system available at rescue station in suppressing the train fire was proven and thus besides undersea tunnel, compressed air foam fire extinguishing system shall be available at other ordinary tunnels after adjusting the nozzle angle and installation position to minimize the fire water and fire extinguishing agent in consideration of advantages of this fire extinguishing system and further test needs to be conducted accordingly.

Acknowledgement

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