Automated Fire Detection and Suppression in a Retrofitted Tunnel Using Fiber-Optic Linear Heat Detection

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Abstract

After the tragic fires in tunnels in Europe (Mont Blanc, Tauern, and St. Gotthard), many European countries decided to push the European commission for tunnel fire safety standards and legislations. While European countries have decided to always have a fire detection system in tunnels, in the United States, very few tunnels have a fire detection system, let alone an active fire protection system. With the objective to best protect the travelling public, prior to retrofitting the 1.7-mile-long Eisenhower-Johnson Memorial Tunnel (EJMT), the Colorado Department of Transportation (CDOT) sought a performance-based system that would first detect different types of fires and deliver the greatest flexibility in suppressing them [2]. For an active fire protection system to be effective, the most important task is the ability to have a system that detects fires very quickly and most importantly accurately by minimizing false alarms. Therefore Linear Heat Detection (LHD) by fiber-optic was selected for its accuracy in reducing false alarms and flexibility for this application.

Linear heat detection (LHD) by fiber-optic (FO) sensing systems has been introduced to the fire detection market about 15 years ago. The FO-LHD technology is based on the temperature-dependent Raman scattering of laser light within optical fibers. The sensing element is a continuous fiber-optic cable with neither electricity nor discrete sensing elements. The FO-LHD technology allows for a continuous measurement of temperature and a precise localization of the thermal event along the passive fiber-optic cable with 1 meter accuracy. Hence, one of its main advantages is its versatility: flexibility to adjust and set the alarm parameters based on set temperature thresholds such as rate of rise, maximum temperature, and differential zonal temperature.

Keywords: Fiber-optic, linear heat detection, LHD, false alarm susceptibility, dust properties, test method, non-fire sensitivity, Raman

Introduction

For the EJMT, CDOT pursued a solution and a design that would be affordable and least impactful to the more than 30,000 vehicles that each day travel through the twin, 1.7-mile-long tunnels near the top of Loveland Pass, two of the highest elevation transportation tunnels in the world.

CDOT had specific design criteria for the active fire protection system. The system had to have the capability to

- Limit a fire with a growth rate of 20 MW per minute to 35 MW;
- To be integrated to the existing tunnel operation and monitoring system;
- Have very short zones (less than 100 feet) for the detection and the suppression;
- Operate two deluge systems (zones) simultaneously for a minimum of 60 minutes;
- Seamlessly blend with the current historic design of the tunnel.

CDOT wanted to perform a real test to ensure the active fire detection and protection system would be properly integrated to meet the above criteria.

The conventional systems such as smoke and flame detectors are often susceptible to false alarms as they react to dust, fumes, water vapor, car lights and vehicle exhaust [1]. Conventional fixed temperature and rate of rise point detectors have been used in tunnels, but they are often limited by their range and the logistics behind their installation. Because of the fact that they measure discrete points only, they have limited distance range and flexibility. The alarm parameters for these systems are already preset. While traditional wire-type Linear Heat Detector could be used for longer ranges, they also have alarm parameters values predefined during their manufacturing. The fiber-optic Linear Heat Detection was selected because of its ability to both monitor temperature and set pre-alarm and alarm criteria programmatically based on the temperatures and rates-of-rises.

Considering its purely optical principle and the absence of electrical energy within the sensing cable, the FO-LHD technology is immune to any electromagnetic interference. The fiber is well protected by a plastic or metallic sensor cable which can resist mechanical load, most chemicals and high radiation levels. The optical energy can be inherently safe limited making the technology compliant to explosive areas. Thus, this technology can be applied in many challenging safety applications and especially in automatic fire detection in most environments, such as tunnels.

Performance-Based Design and Experimental Test

Normally, fire suppression systems are designed in accordance with the NFPA 13 [2]. While using these design rules for fire suppression systems has been proven to be successful, the method did not provide for the flexibility need to integrate the system into the existing architectural features of the tunnel. The use of a performance-based design approach allowed the team to account for the unique aspects of this facility while meeting the CDOT's prescribed goals.

In addition to the selection of the fiber-optic Linear Heat Detection, the design team decided to use a water only deluge system. The evaluation of each type of system weighed factors such as environmental impacts, construction cost and long term maintenance costs [2]. These two choices provided a balance between construction cost, continued maintenance cost and low environmental impact.

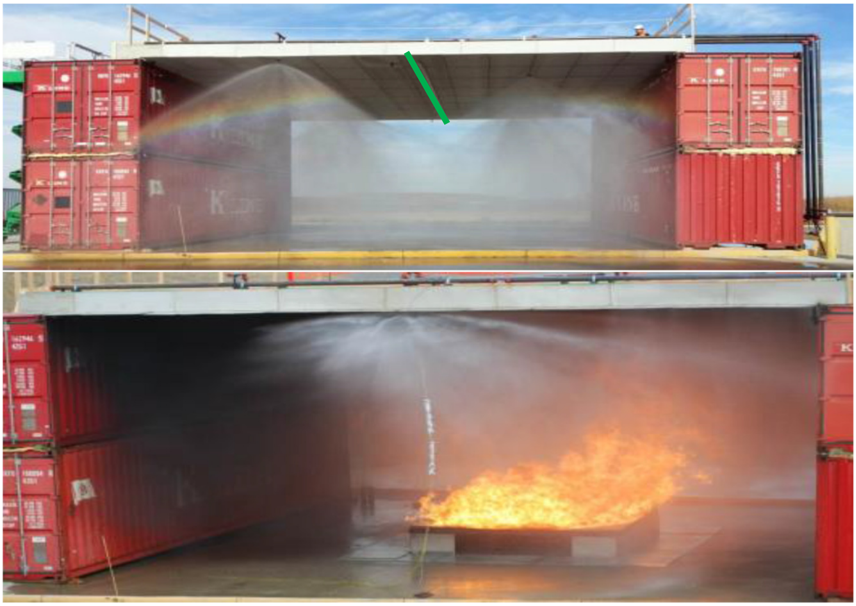

Fig. 1. Mock up test chamber.

As part of the proof of concept and design build process, a replica of the EJMT's roadway space of the tunnel was constructed. The mock up included the fiber-optic Linear Heat Detection (LHD) for fire detection, the suppression and alarm components that were to be used in the actual installation. Additional instrumentation such as thermometers and anemometer were installed that recorded temperature and wind velocity. The acquired data was used to estimate the fire size pre and post deluge system activation. Each system was evaluated using a heptane pool fire in both a shielded and unshielded configuration.

Integration to Eisenhower-Johnson Memorial Tunnel (EJMT)

After the performance based design concept had been proven, the system design and layout needed had to be in-line with the existing tunnel infrastructure. The FO-LHD was installed up in the ceiling in the middle of the two-lane roadways. The system featured two FO-LHD controllers with the cable routed in a Class A configuration so that even if the cable is accidentally damaged, the temperature and the fire detection system would still operate without issues.

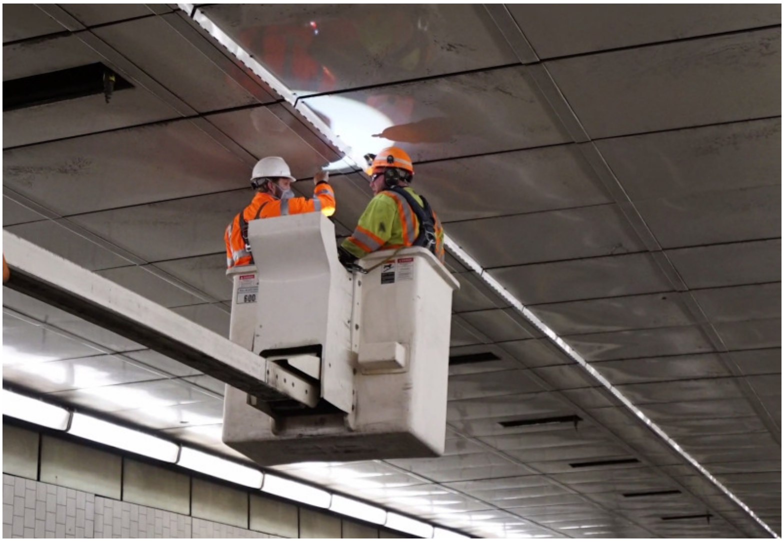

Fig. 2. Installation of FO LHD.

Fig. 3. Integrated active fire protection system.

The set points of the LHD were determined through analyzing recorded ambient temperature data over a three-month period in each tunnel and expected temperatures predicted through the FDS modeling.

The FO-LHD is installed on the ceiling of the road tunnel and monitors the temperature while sectioned in multiple virtual zones. The FO-LHD monitors the tunnel temperature and is set to send pre-alarms and alarms to the main fire alarm panel system. There are twelve (12) pan-tilt-zoom (PTZ) cameras in each tunnel. The cameras are pre-positioned to zones of alarm when a temperature rise of 25 °F/minute is detected. In the event of a sudden and abnormal increase in temperature due to a starting fire, the FO-LHD will first automatically activate two cameras and changing its positions and zoom-in on the corresponding zone.

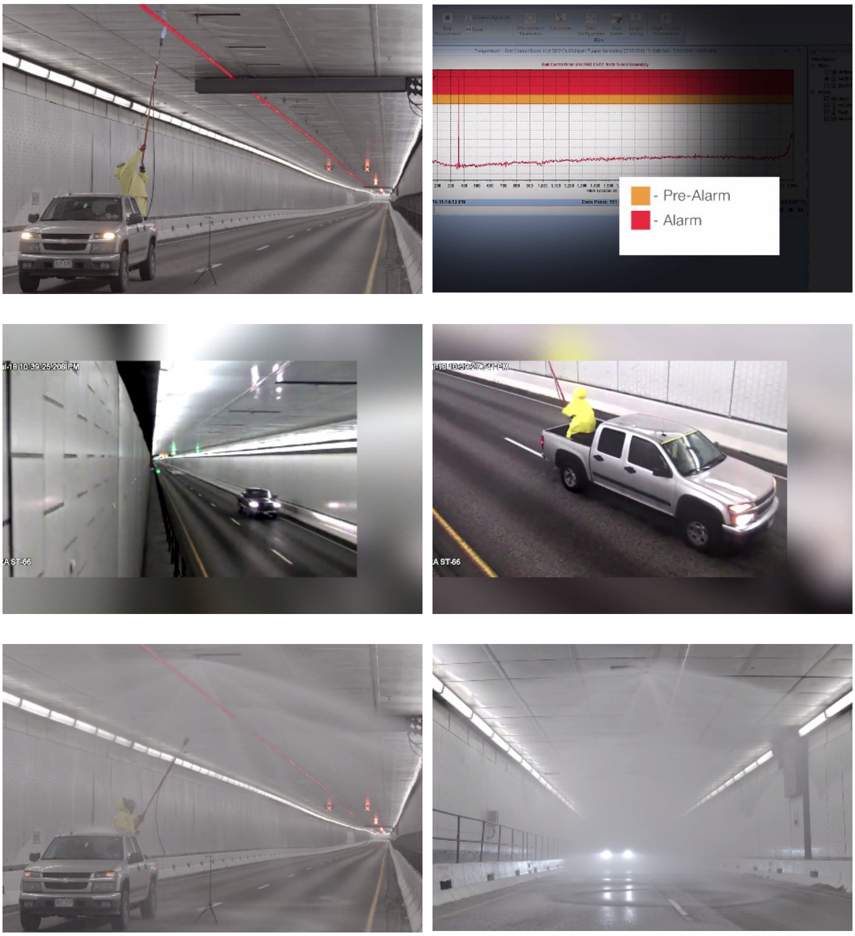

Fig. 4. Illustration of the system's operation during fire trial.

Secondly, in the event the temperature within a zone rise up to reach the defined fire threshold maximum temperature, the FO-LHD system automatically activates the right valve of the suppression system (sprinkling system) to flood the right location and also automatically activates the fans that blow air inside the tunnel to ensure there is proper airflow to ensure air quality of the people inside the tunnel.

Conclusion and Outlook

Colorado Department of Transportation (CDOT) opted to do a performance based design for effective fire suppression. It has been recognized that active fire protection systems can definitely save lives in the event of fire in a tunnel [1].

The fiber-optic Linear Heat Detector (FO-LHD) has been shown to be the optimum fire detection system for active fire suppression systems in the EJMT tunnel. It is essentially a distributed temperature sensing system whose alarm parameters can be modified after the installation, thus achieving a high level of false alarm safety and an early stage alarm response in case of fire. The robustness of the FO sensor cable and the reliability of the LHD controller unit minimize maintenance efforts to a minimum extend. The precision of the localization of a fire event enables to trigger locally parts of the fire suppression system limited to the location of interest. CDOT's specific design criteria have been fully met.

Acknowledgements

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References

[1] Alan Brinson, Active Fire Protection in Tunnels, Fourth International Symposium on Tunnel Safety and Security, Frankfurt am Main, Germany, March 17-19, 2010.

[2] Stephen Rondinelli, Tunnel Fire Protection Project: The Performance-Based Design and Installation of a Fixed Fire System to Protect a Major Interstate Corridor, NFPA Conference 2016.