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# North American Road Tunnel Fire Detection Research Project

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## Abstract

A study to investigate the performance of fire detection systems in roadway tunnels was initiated by the Fire Protection Research Foundation in 1999. A Technical Advisory Group consisting of fire and transportation officials, engineering firms, researchers, and system manufacturers was formed to oversee the project, whose overall goals are:

- Investigate the performance attributes of current fire detection technologies for roadway tunnel protection;
- Develop performance criteria for fire and smoke detection systems in roadway tunnel applications;
- Help optimize the technical specifications and installation requirements for this application.

The first phase of this project that was completed recently was a literature review of past and current research and application of fire detection systems for road tunnel protection. Based on this study, a second phase of the research program with the following objectives was launched in November 2005:

- Develop appropriate design fire scenarios and test protocols for evaluating performance of road tunnel detectors;
- Conduct full-scale tunnel fire tests to document the performance of currently available fire detection technologies under challenging tunnel fire scenarios;
- Analyze technical data and conduct computational modeling to help understand and optimize the technical specifications and installation requirements for application of fire detection technologies in road tunnels;
- Evaluate environmental effects in real tunnel environments on system performance;
- Benchmark full scale fire research scenarios against data from demonstration fire tests;
- Provide technical data to standards and code writers for the development of guidelines for application of fire detection technologies in road tunnels.

The paper will present a summary of the first phase literature study, a progress report on the second phase of the research program, and an update on roadway tunnel research and standards development activities in North America.

## Roadway Tunnels in the United States

Increasing traffic congestion in urban areas and growing land values in the United States make underground structures increasingly attractive for highways and transit compared to other options. A tunnel can preserve the land above for parks, buildings, homes and other uses while providing an efficient, cost-effective underground corridor to move people and goods. Unfortunately, only limited national guidelines, standards, or specifications are available for tunnel design, construction, safety inspection, traffic and incident management maintenance, security, and protection against natural or man-made disasters. Table 1 shows the current inventory of roadway tunnels in the United States.

**Table 1. Federal Highway Administration Asset Management Report**

| State | Number of Tunnels |
|---|---|
| WA | 48 |
| CO | 36 |
| NC | 29 |
| DC | 18 |
| VA | 17 |
| PA | 17 |
| MN | 12 |
| TN | 10 |
| NY | 10 |

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| State | Length (ft) |
|---|---|
| PA | 78,270 |
| NY | 72,129 |
| VA | 63,710 |
| CO | 41,012 |
| MD | 30,551 |
| WA | 29,652 |
| MA | 28,280 |
| HI | 18,720 |
| NC | 17,338 |

## North American Standards

### National Fire Protection Association (NFPA)

NFPA 502, Standard on Road Tunnels, Bridges and Other Limited Access Highways, has been in existence since 1980. Since that time it has undergone six revisions, during which it changed from a recommended practice to a standard and continued to add requirements ranging from emergency ventilation to emergency egress.

The most recent edition (2004) includes new requirements for the protection of concrete and steel tunnel structures, specific requirements for emergency lighting, and clarification of the travel distance to emergency exits. This edition also updated the vehicle tunnel fire data in Annex A to correlate with recent international research on vehicle fire sizes.

The standard is presently in a revision cycle for the 2007 edition. In this edition the committee will be specifically focused on the following topics:

- Emergency egress especially walkways, egress marking and signage and issues surrounding those with mobility impairments;
- Developing a matrix of relevant codes and standards of practice that are currently either adopted by other countries or published by other entities. This matrix is intended to serve as a repository of known requirements or recommendations that will provide the technical committee a single point reference on various areas/subjects of concern in road tunnel safety;
- Evaluating the use of and requirements for fixed fire protection systems in tunnels;
- Public education on tunnel safety;
- Considerations for the definition of a tenable environment;
- Electrical and fire detection systems requirements; and
- Structural fire resistance in light of recent vehicle fire research.

The committee will produce two preparatory documents for public review: the Report on Proposals, summer 2006 and the Report on Comments, February 2007. All information is publicly available on the NFPA website.

### American Association of State Highway and Transportation Officials (AASHTO)

Based on an increased concern for safety and security in the U.S. inventory, recently, the AASHTO Subcommittee on Bridges and Structures created a new committee, the Technical Committee on Tunnels (T-20), to help address this problem. T-20 will take the lead in the development of AASHTO guidelines for existing and new tunnels, working with the National Fire Protection Association (NFPA), the Federal Highway Administration (FHWA) and others with respect to standards and guidelines for highway and passenger and freight rail tunnels.

In preparation for the activities of the Technical Committee, an eleven-member team was formed to study European practices on the aforementioned topics. This team consisted of three representatives from FHWA, four representatives from State departments of transportation (DOTs), and others. The scan was sponsored by FHWA, AASHTO, and the National Cooperative Highway Research Program (NCHRP). During late September and early October 2005, the team visited Norway, Denmark, Sweden, France, and Switzerland. In addition, the team had meetings with representatives from The Netherlands, Germany, Italy, and Austria. These countries were selected based on findings from a desk scan that showed them to be innovators in underground transportation systems. The focus of the scan was on equipment, systems, and procedures incorporated into modern underground and underwater tunnels by leading international engineers and designers. Team members identified a number of underground transportation system initiatives and practices that varied from those in the U.S. in some respect. The team recommended that nine of these initiatives or practices, be considered for further study in the United States.

Among the priorities identified was an evaluation of the effectiveness of automatic incident detection systems and intelligent video for tunnels. The scan team learned of sophisticated software that, using a computer system interfacing with ordinary video surveillance cameras, automatically detects, tracks and records incidents. As it does so, it signals the operator to observe the event in question, and allows the operator the opportunity to take the appropriate action. This concept can also be applied to detect other activities and incidents in areas besides tunnels, from terrorist activities to accidents, vandalism and other crimes, fires and vehicle breakdowns.

**Fire Detection Research at the Fire Protection Research Foundation**

A study to investigate the performance of fire detection systems in roadway tunnels was initiated by the Fire Protection Research Foundation in 1999. Phase I of the project, completed in 2003, was a review of available tunnel fire detection technology, a synopsis of reported major tunnel fires and the means of detection, and a review of road tunnel fire tests. The reports of road tunnel fire incidents compiled in this report indicate that first generation installed fire detectors have not been effective in providing the first notice of fire occurrence. A database of forty fire tests involving road tunnel detectors was developed as part of the project, most involving pool fire tests with heat release rates up to about 3 MW. Most of the tests involved linear heat detectors installed in tunnels with longitudinal ventilation and generally good performance was measured.

As a result of the review, recommendations for further research were made in the following areas:

- Additional types of fire detection technologies (e.g. flame detection, CCTV, etc);
- Additional fire scenarios, including variable heat release rates and moving fire sources; and
- Varying ventilation conditions, particularly transverse ventilation.

## International Road Tunnel Fire Detection Research Project

In 2005, The National Research Council of Canada (NRCC) and the Fire Protection Research Foundation (FPRF), with support of government organizations, industry and private sector organizations, initiated the Phase II of an international project that aims to investigate the application of current fire detection technologies for roadway tunnel protection. The project includes studies on the detecting performance of current fire detection technologies with both laboratory and field fire tests combined with a computer modeling study, as well as their reliability and availability in real roadway tunnel environments. The goals of the program are to:

- Develop appropriate design fire scenarios and test protocols for evaluating performance of road tunnel detectors;
- Conduct full-scale tunnel fire tests to document the performance of currently available fire detection technologies under challenging tunnel fire scenarios;
- Analyze technical data and conduct numerical simulations to help understand and optimize the technical specifications and installation requirements for the application of fire detection technologies in road tunnels;
- Evaluate environmental effects on system performance in operating tunnel settings;
- Benchmark full scale fire research scenarios against data from demonstration fire tests in road tunnels; and,
- Provide technical data to standards and code writers for the development of guidelines for application of fire detection technologies in road tunnels.

## Performance Criteria and Detection Technologies

Three basic performance criteria for a fire detection system in tunnel application are adopted in the project: namely, capability, reliability and availability.

The detecting capability criterion implies that a fire detecting system shall quickly respond to a fire incident in its initial stage. At the same time, the system shall provide information on the fire incident such as its location, developing direction and size.

The second performance criterion entails that the fire detector shall be reliable to respond fire incidents and not be influenced by the emission of pollutants from vehicles and ventilation. In other words, its false alarm rate shall be controlled to an acceptable level.

The third criterion implies that the fire detection system shall be available to work properly in harsh tunnel environments. Tunnel environment can involve significant changes during daily operation in temperature and level of air pollutants emitted from vehicles. Such harsh environment shall not block the operation of the system.

There are five possible fire detection technologies used for tunnel protection [5]. They are: linear heat detection systems, flame detectors, CCTV fire detectors, smoke detection systems and spot detectors. The features of these technologies and their applications in

tunnel are listed in Table 2.

**Table 2 Current available tunnel fire detection technologies**

| | Linear heat detectors | Flame detectors | CCTV detectors | Smoke detectors | Spot detectors |
|---|---|---|---|---|---|
| **Detecting principle** | Heat | Radiation | Image | Smoke | Heat, smoke, gas, etc. |
| **Detecting capability** | Response to be determined; Locating and monitoring fires; | Fast response; Locating fires; | Fast response; Locating & monitoring fires | Fast response; Locating fires; | Moderate response; Locating fires; |
| **Reliability** | High | To be determined | To be determined | Low | Moderate to high |
| **Availability** | High | To be determined | To be determined | Moderate | Moderate to high |
| **Applications** | Europe | Japan | None | None | Sprinkler head |

Linear heat detection systems are the primary detecting technology used in European tunnels, while flame detectors are mainly used in Japanese tunnels [6, 7, 13]. Sprinklers, as spot heat detectors, are installed in some tunnels around the world. CCTV cameras are already widely applied in tunnels for incident prevention and management. There is significant interest in extending tunnel CCTV cameras into automated fire detection. Roadway smoke detection systems, such as smoke beam detectors and plenum and duct smoke detectors, have fast response time to a fire incidence, however, false alarm problems associated with diesel engine and ill-maintained vehicle exhaust in tunnels seem to preclude any widespread use of these detection systems in tunnels. According to currently available technologies, four fire detection technologies will be investigated in the project. They are:

- Line heat detectors, such as thermistor type, heat sensitive polymer type, fiber optic sensing cables, pneumatic type, etc.;
- CCTV flame and smoke detectors;
- Flame detectors that sense radiation emitted from a fire; and
- Sprinkler heat detectors.

2 different fire detection systems for each type of technology will be evaluated in the testing program.

**Tasks**

Six tasks will be carried out as part of this project to study the detecting performance of

current fire detection technologies and their reliability and availability in roadway tunnel environment.

Task 1 will be focused on designing appropriate tunnel fire scenarios and test protocols, as well as constructing testing fire sources. Three types of fire scenarios, that are encountered in the majority of tunnel fire incidents, are selected for use in evaluating the performance of the road tunnel detectors in the project:

- A liquid pool fire caused by fuel leaking from a vehicle or by collision incidents. The fire develops very quickly and reaches its maximum heat release rate in a short time;
- A stationary passenger vehicle fire caused by collision incidents, by an electrical failure or by a defective fuel delivery systems and exhaust system failures. The fire develops slowly and it takes 8 ~ 12 minutes for a car fire to reach its maximum heat release rate [4, 17, 18];
- A moving vehicle fire caused by an electrical failure or by defective fuel delivery systems or exhaust system failures. The fire is small and develops slowly.

The fire growth and development characteristics of the three fire sources, such as heat release rate, fire growth rate and radiation, will be investigated in Task 1.

Task 2 is a series of large scale laboratory tunnel fire tests that are conducted in a new facility jointly developed by Carleton University and NRCC. Design tunnel fire scenarios, testing protocols and testing fire sources will be studied in the lab tunnel tests, which ensures that they satisfy the requirements for the project. Performance of four tunnel fire detection technologies will then be investigated in lab tunnel tests with the most challenging fire scenarios. Response time of a fire detection system to a variety of fire scenarios with different fuel type, fire size and location will be studied, and continuous fire product data, such as temperature, $O_2$, $CO_2$, and CO concentrations and smoke concentrations, and their influences on performances of the detection system will be monitored and recorded continuously from ignition in collaboration with the detector manufacturers.

CFD modeling, based upon NRCC's previous studies [19], will be carried out in Task 3 to study the fire growth and smoke movement in the tunnel under various fire scenarios, tunnel operating conditions and tunnel geometries. Information obtained from CFD modeling will be used to develop appropriate test protocols to understand and optimize the detection system performance..

Task 4 is the conduct of field fire tests in an operating road tunnel in the city of Montreal, Canada in collaboration with Ministry of Transport of Quebec (MTQ). The performance and installation criteria of fire detection systems for road tunnel protection will be investigated in four fire scenarios, including a moving vehicle fire, a pool fire and two simulating stationary passenger vehicle fires. The tunnel ventilation in the tests will be maintained under normal operating conditions. The data collected in each series of fire tests will include the detection time of the fire detection system for a fire incident,

temperature distribution, gas compositions, smoke movement and air velocity in the tunnel. The whole testing process will be recorded using video cameras.

In order to determine the influence of environmental conditions on the performance of fire detection systems, Task 5 will involve field installations of fire detection systems carried out in the Lincoln and/or Holland Tunnels in cooperation with the Port Authority of New York and New Jersey (PANYNJ). These installations will be monitored over a one year period. The false alarms generated by the detection systems, environmental conditions, and maintaining requirements for the systems will be recorded.

Task 6 will involve one or more full-scale fire tests in the Lincoln and/or Holland Tunnels. Theses tests will provide valuable information to validate results of computer models developed and will be refined using full-scale laboratory and field tests in the city of Montreal, since the geometry and ventilation conditions of the Lincoln and Holland Tunnels are different from those in the lab tunnel and Montreal tunnels.

**Project Status**

The project was launched on November 2005 and will be completed in a two-year period. The first four tasks are being undertaken by NRCC. Tasks 5 and 6 will be carried out in collaboration with the Port Authority of New York & New Jersey under direction of the fire Protection Research Foundation. A Project Technical Panel has been formed whose members include government organizations, university and research organizations, tunnel authorities, fire detection manufacturers, engineering consultants, and code and standard writers.

It is expected that the outcome of the project will provide a better understanding of the factors that influence the performance of fire detection systems in roadway tunnels under routine and fire conditions. This will lead to the optimization of tunnel design and installation criteria for detection systems to enhance the safety of roadway tunnels. Information from the project will be of value to manufacturers, designers, tunnel authorities and standards and code writers, and will lead to further optimization of the installation of detection systems and development of guidelines for this unique application.

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