# Overview of NFPA 502 *Standard for Road Tunnels, Bridges and Other Limited Access Highways*, 2008 Edition

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**ABSTRACT:** NFPA 502, *Standard for Road Tunnels, Bridges and Other Limited Access Highways* establishes minimum fire protection and fire life safety requirements for road tunnels, bridges and other roadways where access by emergency responders is physically limited.

The 2008 edition of NFPA 502 represents the Technical Committee's consensus of current best practice for fire protection and life safety requirements for road tunnels, bridges and similarly limited access highways. Research of national and international test programs, design guidelines and regulating standards was performed and considered in an effort to establish a singular, comprehensive document representing a recognized base threshold of fire safety in these type facilities.

This paper provides an overview of the more significant revisions including the application of fixed fire suppression systems, guidance on tenable environment, protection of structure and dangerous goods transport.

## INTRODUCTION

In recent years road tunnel fires and subsequent international research projects suggest that vehicle fires within tunnels are likely to develop more rapidly than expected, degrade the tenability of an environment more quickly than originally calculated, and have the potential to burn for longer periods of time and at higher temperatures that may resist intervention of fire fighting operations.

In light of this the NFPA Technical Committee on Road Tunnel and Highway Fire Protection determined it timely for NFPA 502 *Standard for Road Tunnels, Bridges and Other Limited Access Highways* to revisit a number of its provisions with respect to fires in road tunnels. The 2008 edition includes revisions that further clarify the categorization of road tunnels, a revision of the discussion topics in the Annex on fixed fire suppression systems, and revisions regarding tenable environment, protection of structure and the transport of potentially dangerous cargoes.

In particular there has been a broad reconsideration of the requirements and recommendations for:

- Application of fixed water-based fire suppression systems
- Protection of structure and structural elements
- Maintaining a tenable environment
- Transport of regulated and unregulated cargoes

Several other modifications have been made throughout the Standard that are intended to capture the latest thinking on the best practices for fire and life safety provisions. Annex material has been added and expanded to share relevant information and source material related to specific provisions.

## APPLICATION OF FIXED FIRE SUPPRESSION SYSTEMS

The use and effectiveness of fixed water-based fire suppression systems in road tunnels is still not universally accepted. However, recent research through full-scale testing and real life operational experience has demonstrated that fixed fire fighting systems can be effective in controlling vehicle fires in road tunnels by limiting the spread of the fire, reducing the temperature of surrounding air and surfaces, and reducing the fire heat release rate.

One of the reasons why many countries have been reluctant to use fixed fire suppression systems in road tunnels is that most vehicle fires start in the motor compartment,, and fixed fire suppression systems are of limited use in suppressing the fire until the fire is out in the open. Fixed fire suppression systems can be used, however, to cool down vehicles, to stop the fire from spreading to other vehicles (i.e., to diminish the fire area and property damage), and to stop secondary fires in tunnel lining materials. Experiences in Japan and Australia show that fixed fire suppression systems are effective in cooling down the area around the fire site, so that fire fighting can be performed more effectively.

The 2008 Edition of NFPA 502 now includes guidance for the installation of fixed water-based fire suppression systems and has revised annex language which acknowledges the potential benefits of fixed fire fighting systems in road tunnel application.

Specifically, Annex E now suggests the consideration of fixed fire suppression systems when it can be shown by engineering analysis that the level of safety can be equal or exceeded by their use as part of an integrated approach to the management of life safety. Annex E also addresses, as follows, the previously listed concerns which had been expressed by tunnel designers, engineers and worldwide (authorities) regarding the application of fixed fire fighting system in road tunnels:

> Concern (1) Typically fires in road tunnels usually occur inside vehicles or inside passenger or engine compartments designed to be waterproof from above; therefore, fixed fire fighting systems might not have an extinguishing effect.
>
> *It is now recognized that the purpose of a fixed fire fighting fire suppression system is to prevent fire spread to other vehicles so that the fire does not grow to a size that cannot be attacked by the fire service.*
>
> Concern (2) If any delay occurs between ignition and fixed fire fighting system activation, a thin water spray on a very hot fire could produce large quantities of superheated steam without material suppressing the fire.
>
> *Fire tests have now shown this concern not to be valid. A properly design fixed fire fighting system suppresses the fire and cools the tunnel environment. Since a heavy goods vehicle fire only needs 10 minutes to exceed 100 MW and 1200°C, which are fatal conditions, it is important to operate the fire suppression system as soon as possible.*
>
> Concern (3) Tunnels are very long and narrow, often sloped laterally and longitudinally, vigorously ventilated, and never subdivided, so heat normally will not be localized over a fire.
>
> *Nevertheless advances in fire detection technology have now made it possible to pinpoint the location of a fire in a tunnel with sufficient accuracy to operate a zoned fixed fire fighting system.*
>
> Concern (4) Because of stratification of the hot gas plume along the tunnel ceiling, a number of the activated sprinklers would not, in all probability, be located over the fire. A large number of the activated sprinklers would be located away from the fire scene, producing a cooling effect that would tend to draw this stratified layer of smoke down toward the roadway level, thus impeding the rescue and fire fighting effort.
>
> *Independent laboratories have commented that they do not observe smoke stratification. Any activated fixed fire fighting system, not over the fire, would cool the tunnel to help rescue services to intervene. Zoned systems are released by a detection system that is accurate even with forced ventilation.*
>
> Concern (5) Water spraying from the ceiling of a subaqueous tunnel could suggest tunnel failure and induce panic in motorists.
>
> *This was a theoretical concern not borne out in practice. In the event of fire motorists are likely to recognize water spraying from nozzles as a fire safety measure. Behavioral studies have shown that people do not panic in a fire, even when they are unable to see.*
>
> Concern (6) The use of sprinklers could cause the delamination of the smoke layer and induce turbulence and mixing of the air and smoke, thus further threatening the safety of persons in the tunnel.
>
> *This has been shown not to be a valid concern. Fire tests have demonstrated that smoke does not usually form a layer at the top of the tunnel but quickly fills the cross-section. Normal air movement in the tunnel accelerates this process. A fixed fire fighting fire suppression system reduces temperatures and the risk of fire spread to other vehicles.*
>
> Concern (7) Testing of a fixed fire fighting system on a periodic basis to determine its state of readiness could be impractical and costly. Inspection can be performed when other facilities are inspected.
>
> *A full discharge test is normally only performed at system commissioning. During routine testing the system can be configured to discharge flow to the drainage system.*

## PROTECTION OF STRUCTURE AND STRUCTURAL ELEMENTS

In the last edition (2004) NFPA 502 introduced new requirements for the protection of structural elements within road tunnels. The 2008 edition has

been significantly revised to provide specific guidance for the evaluation structural fireproofing requirements. The following requirements have been included to further support road tunnel design requirements as they pertain to both life safety and protection of property:

- *Regardless of tunnel length, all primary structural concrete and steel elements shall be protected in accordance with this standard in order to:*
  - Maintain life safety and provide a tenable environment.
  - Mitigate structural damage and prevent progressive structural collapse.
  - Minimize economic impact.
- The structure shall be capable of withstanding the Rijkswaterstaat (RWS) (Netherlands) time / temperature curve, or other curve that is acceptable to the Authority Having Jurisdiction.

The time/temperature development is shown in the table below:

| Time (Minutes) | Temp °C | Temp °F |
|---|---|---|
| 0 | 20 | 68 |
| 3 | 890 | 1634 |
| 5 | 1140 | 2084 |
| 10 | 1200 | 2192 |
| 30 | 1300 | 2372 |
| 60 | 1350 | 2462 |
| 90 | 1300 | 2372 |
| 120 | 1200 | 2192 |

- After 120-minute period of fire exposure, the following failure criteria shall be satisfied:
  - Tunnels with cast in-situ concrete structural elements shall be protected such that:
    i. The temperature of the concrete surface does not exceed 380°C (716°F).
    ii. The temperature of the steel reinforcement within the concrete (assuming a minimum cover of 25mm (1 in.) does not exceed 250°C (482°F).
  - Tunnels with pre-cast, high-strength concrete elements shall be protected such that explosive spalling is prevented.
  - Steel or cast iron tunnel linings shall be protected such that the lining temperature shall not exceed 300°C (572°F).
  - Structural fire protection material shall be non-combustible in accordance with ASTM E 136 or equal international standard.
    i. It shall have a minimum melting temperature of 1350°C (2462°F).
    ii. It shall not produce toxic smoke or fumes under fire exposure in accordance with ASTM E 84 or equal international standard.
    iii. It shall meet the fire protection requirements with <5% humidity by weight and also when fully saturated with water in accordance with RWS Fire Test Procedure 1998-CVB-R1161 (Rev 1).
  - Any fire protection material should satisfy the following performance criteria:
    i. Be resistant to freezing and thawing
    ii. Withstand dynamic suction and pressure loads
    iii. Withstand both hot and cold thermal shock from fire exposure and hose streams
    iv. Meet all applicable Health and Safety Standards
    v. Not itself become a hazard during a fire
    vi. Be resistant to water ingress
  - The level of fire resistance of structures and equipment must be proven by testing or reference to previous testing. Fire test reports are based on the following requirements:
    i. Concrete slabs used for the application of fire protection materials for fire testing purposes have dimensions of at least 1400×1400 mm and a nominal thickness of 150 mm.
    ii. The exposed surface will be approximately 1200×1200 mm.
    iii. The fire protection material must be fixed to the concrete slab using the same fixation material (anchors, wire mesh, etc.) as will be used during the actual installation in the tunnel.
    iv. In the case of board protection, minimum one joint in between two panels must be created, in view to judge if any thermal leaks will occur in the case of a real fire in the tunnel.
    v. In case of spray materials, the number of applications (amount of layers) must be registered when preparing the test specimen. This amount of layers must be respected while applying the spray material in a real tunnel.
    vi. Temperature recordings by thermocouples located:
      a. At the interface in between the concrete and the fire protection material
      b. At the bottom of the reinforcement
      c. On the non-exposed face of the concrete slab

## MAINTAINING A TENABLE ENVIRONMENT

The 2008 Edition includes a complete revision to the annex material relating to tenable environment. This is intended to correlate with similar guidance material in NFPA 130, *Standard on Fixed Guideway Transit and Passenger Rail Systems*. The purpose of the annex is to provide guidelines for the evaluation of tenability within the tunnel evacuation paths. Current technology is capable of analyzing and evaluating all unique conditions of each path to provide proper ventilation for pre-identified emergency conditions. The same ventilating devices might or might not serve both normal operating conditions and pre-identified emergency requirements. The goals of the ventilation system, in addition to addressing fire and smoke emergencies, are to assist in the containment and purging of hazardous gases and aerosols such as those that could result from a chemical/biological release.

Environmental conditions, geometric considerations, and time considerations should be taken into account. Following are some factors that should be considered in maintaining a tenable environment for periods of short duration.

### Heat Effects

Exposure to heat can lead to life threat three basic ways:

- Hyperthermia
- Body surface burns
- Respiratory tract burns

For use in the modeling of life threat due to heat exposure in fires, it is necessary to consider only two criteria—the threshold of burning of the skin and the exposure at which hyperthermia is sufficient to cause mental deterioration and thereby threaten survival.

### Air Carbon Monoxide Content

Air carbon monoxide (CO) content should be as follows:

- Maximum of 2000 ppm for a few seconds
- Averaging 1150 ppm or less for the first 6 minutes of the exposure
- Averaging 450 ppm or less for the first 15 minutes of the exposure
- Averaging 225 ppm or less for the first 30 minutes of the exposure
- Averaging 50 ppm or less for the remainder of the exposure

These values should be adjusted for altitudes above 984 m (3000 ft).

### Smoke Obscuration Levels

Smoke obscuration levels should be continuously maintained below the point at which a sign internally illuminated at 80 lx (7.5 ft-candles) is discernible at 30 m (100 ft) and doors and walls are discernible at 10 m (33 ft).

### Air Velocities

Air velocities in the enclosed tramway should be greater than or equal to 0.76 m/s (150 fpm) and less than or equal to 11.0 m/s (2200 fpm).

### Noise Levels

Noise levels should be a maximum of 115 dBA for a few seconds and a maximum of 92 dBA for the remainder of the exposure.

## TRANSPORT OF REGULATED AND UNREGULATED CARGOES

Recent road tunnel fires suggest that goods traditionally not characterized as ‘hazardous’; i.e. flour and margarine (1999 Mont Blanc Tunnel), paint (1999 Gothard Tunnel), and tires (2005 Frejus Tunnel), may constitute a greater risk to tunnel users and tunnel structures than expected. As a result Chapter 13 Control of Hazardous Materials has been re-titled Regulated and Unregulated Cargoes to provide guidance to tunnel operators, first responders and enforcement officials on developing rules regarding any and all cargoes allowed passage through a particular road tunnel facility.

The authority having jurisdiction must adopt rules and regulations that apply to the transportation of regulated and unregulated cargoes. Design and planning of the facility must address the potential risk presented by regulated and unregulated cargoes.

When developing vehicle cargo regulations for a particular road tunnel facility, fire, accident, and research experience of the vehicles and cargo of the type expected within the tunnel—and particularly of goods and vehicles not normally characterized as hazardous or otherwise regulated—should be considered. Some types of cargoes not normally considered hazardous may in certain circumstances in confined spaces within tunnels behave as, or equivalent to, hazardous materials in terms of the rate of fire growth, the intensity of the fire, discharge of noxious materials, destruction to infrastructure, and threat to users’ safety.

In developing regulations, the following must be addressed:

1. Population density
2. Type of highway
3. Types and quantities of hazardous materials

4. Emergency response capabilities
5. Results of consultation with affected persons
6. Exposure and other risk factors
7. Terrain considerations
8. Continuity of routes
9. Alternative routes
10. Effects on commerce
11. Delays in transportation
12. Climatic conditions
13. Congestion and accident history

## SUMMARY

The 2008 Edition of NFPA 502 is intended to correlate the fire and life safety provisions that are based on the latest research, technologies, and real-life lessons learned so that tunnel designers, engineers, first responders, and operating authorities have an immediate source recognized requirements for creating a fire safe road tunnel environment.

The NFPA 502 Technical Committee fully anticipates that ongoing research programs being conducted both nationally and internationally such as The International Road Tunnel Fire Detection Research Project sponsored by The Fire Protection Research Foundation, the Large-Scale Fire Heat Release Rate Tests conducted by a variety of consortiums in collaboration with UPTUN and the SP Swedish National Testing and Research Institute, and sprinkler system testing such as that conducted by The Netherlands Organisation for Applied Scientific Research, will continue to yield valuable information. As the Technical Committee looks forward to the development of the 2011 Edition of NFPA 502 it fully recognizes that diligent attention to the results of these research programs is necessary so that fair evaluation and consensus of results can be expeditiously considered for incorporation.