Committee Input No. 67-NFPA 502-2014 [ New Section after 4.3 ]

New proposed section 4.3.1 ***see attached word document***

Supplemental Information

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Submittal Date: Fri Dec 12 13:37:02 EST 2014

Committee Statement

Committee Statement: Provides criteria and annex guidance for performing an engineering analysis in lieu of prescriptive requirements.

Response Message:
4.3.1 **Engineering analysis**  
4.3.1.1 Regardless of length of the facility, as a minimum, the following factors shall be fully considered as part of an engineering analysis of the fire protection and life safety requirements for the facilities covered by this standard for the protection of life in the facility:

1. Users of the facility
2. Restricted vehicle access and egress
3. Fire emergencies ranging from minor incidents to major catastrophes
4. Fire emergencies occurring at one or more locations inside or in close proximity to the facility
5. Fire emergencies occurring in remote locations at a long distance from emergency response facilities
6. Exposure of emergency systems and structures to elevated temperatures
7. Traffic congestion and control during emergencies
8. Built-in fire protection features, such as the following:
   - Fire alarm and detection systems
   - Standpipe systems
   - Water-based fire-fighting systems
   - Ventilation systems
   - Emergency communications systems
   - Protection of structural elements
9. Facility components, including emergency systems
10. Evacuation and rescue requirements
11. Emergency response time
12. Emergency vehicle access points
13. Emergency communications to appropriate agencies
14. Vehicles and property being transported
15. Facility location, such as urban or rural (risk level and response capacity)
16. Physical dimensions and configuration, including roadway profile
17. Natural factors, including prevailing wind, and pressure conditions
18. Anticipated cargo
19. Impact to buildings or landmarks near the facility
20. Impacts to facility from external operations and/or incidents
21. Traffic operating mode unidirectional, bidirectional, switchable, or reversible
4.3.1.2 In case the engineering analysis is used to deviate from the mandatory requirements, the resulting safety level and availability shall be at least equivalent to the safety level and availability achieved by applying the mandatory requirements.

4.3.1.3 The relative importance of life safety, firefighter safety and economic impact in the safety level and availability shall be defined based on the requirements of the stakeholders, including the AHJ.

4.3.1.4* The equivalence referred to in 4.3.1.2 and the relative importance as referred to in 4.3.1.3 shall be assessed by means of a quantitative risk assessment (QRA) and a cost benefit analysis (CBA).

A.4.3.1.4 The analyses should be performed by a body which is functionally independent from the agency. The content and the results of the risk analysis shall be included in the safety documentation submitted to the AHJ. A risk analysis is an analysis of risks for a given tunnel, taking into account all design factors and traffic conditions that affect safety, notably traffic characteristics and type, tunnel length and tunnel geometry, as well as the forecast number of heavy goods vehicles per day. *(from 2004/54/EC)*

More specifically the risk analysis should include an assessment of the factors in 4.3.1 taking into account the probabilities and consequences for possible values for the given factors. Therefore one should take into account:

(a) all possible scenarios
(b) the probabilities of occurrence for these scenarios
(c) the consequences in terms of loss of lives, damage to the facility and economic costs for each of these scenarios
(d) determine the scenarios to take into account (threshold)

Guidance and background documentation for risk assessment and cost benefit analysis can be found in:


3.3.54 Quantitative risk assessment (QRA). A formalized specialist method for calculating group, individual and environmental risk levels for comparison with governing risk criteria.

3.3.55 Cost Benefit Analysis (CBA). A systematic process for calculating and comparing benefits and costs of a project, decision or government policy.
Committee Input No. 58-NFPA 502-2014 [Section No. 6.2.1]
6.2.1

For bridges or elevated highways less than 300 m (1,000 ft) in length, the provisions of this standard shall not apply.

6.3.1 * Regardless of bridge or elevated highway length, acceptable means shall be included within the design of the bridge to prevent progressive structural collapse of all primary structural elements in accordance shall be protected in accordance with this standard in order to with this standard to achieve the following functional requirements:

(1) Maintain Life safety

(2) Mitigate structural damage and prevent progressive structural collapse Support fire fighter accessibility

(3) Minimize economic impact by mitigating structural damage

6.3.2 * Where the AHJ, based on engineering analysis, has determined that collapse of the bridge will impact life safety, have unacceptable implications due to the loss of the bridge and/or damage/replacement cost; the bridge, including its primary structural members, shall be capable of withstand the time-temperature exposure represented by the respective design fire at the locations recommended in the annex of this Standard, following an engineering analysis as is required in Chapter 4.

6.3.3 * The design fire shall be characterized by location, vehicle type and fuel type, and includes evaluation with the fuel source at the locations recommended in A.6.3.2, as follows:

(1) Except for a bridge spanning over a freeway or interstate highway, for bridges spanning over moving traffic, the design fire shall be a Heavy Goods Vehicle with a fire duration of 120 minutes, positioned at the locations recommended in A.6.3.2. The design fire for a bridge spanning over a freeway or interstate highway shall be a large-pool hydrocarbon tanker truck fire with a fire duration of 45 minutes positioned at the locations recommended in A.6.3.2.

(2) Where applicable, bridges shall be evaluated for a hydrocarbon tanker truck spill fire above the superstructure deck with the spilled fuel entering the bridge deck drainage system.

(3) The AHJ may authorize a reduction in the fire duration, based on the response time and capabilities of the emergency response team.

(4) Where a bridge spans a navigable waterway, the design vehicle (vessel) shall be acceptable to the AHJ following an engineering analysis of the cargo composition using the waterway.

(5) Where a bridge spans a rail line, the design vehicle shall be acceptable to the AHJ following an engineering analysis of the cargo composition using the rail line.

(6) Other recognized standard design fire or recognized standard time-temperature curve that is acceptable to the AHJ.

6.3.4 * Where the AHJ, based on engineering analysis, has determined that collapse of the bridge will impact life safety, have unacceptable implications due to the loss of the bridge and/or damage/replacement cost; structural elements shall be protected to achieve the following performance criteria:

(1) Concrete structural elements shall be designed such that fire-induced progressive spalling is prevented.

(2) The temperature of the cast-in-situ concrete surface does not exceed 400?C (752?F).
Pre-cast concrete is protected such that fire induced progressive spalling is prevented.

The temperature of the steel reinforcement with the concrete (assuming a minimum cover of 25 mm (1 in.)) does not exceed 250°C (482°F).

Steel structural elements shall be protected in order to prevent loss of strength of the element, structural collapse, or the inability of the structure to perform its function such that the steel surface temperature will not exceed 300°C (572°F).

A.6.3.1 Primary structural elements that should be considered can be constructed, for example, out of concrete, steel, masonry, timber, fiber reinforced plastics (FRP) or cast-iron.

Preventing progressive structural collapse and mitigation of structural damage should include analyses of the following effects of the fire on the primary structural elements:

1. Loss of strength, causing failure due to breaking/yielding
2. Loss of stiffness, causing large and plastic deformations
3. Loss of durability due to cracking which could lead to structural collapse (taking into account that some cracking, both during the fire and post-fire, can occur at the non-visible external perimeter of the structure, which cannot be detected nor repaired)
4. Specifically for concrete: fire induced spalling which could lead to structural collapse

Reference for item (3) above is made to:


A.6.3.2 The design fire should be located at the following locations:

1. Location A - Fire source centered at mid-span under the bridge deck spanning traffic below, both longitudinally and transversely.
2. Location B - Fire source centered at mid-span under the bridge deck spanning traffic below longitudinally, but transversely offset to be outside of an exterior girder, and
3. Location C - Fire source transversely centered under the bridge but longitudinally offset close to the pier at the end of the span over traffic below.
4. Location D – Spill fire source on the bridge superstructure deck, with the spilled product entering the bridge drainage system.
5. Location E – Known or planned other fire load locations under the bridge
6. Location F - Other locations based on engineering judgment and analysis.

A.6.3.3 Refer to Table A.11.4.1 – Fire Data for Typical Vehicles to determine Representative Heat Release Rate and Peak Heat Release rate.

Additional information for engineering analysis can be found in NCHRP Project 12-85: Highway Bridge Fire Hazard Assessment – Guide Specification for Fire Damage Evaluation in Steel Bridges. This Guide Specification is intended to assist engineers with evaluation of highway bridge structures following fire events. This document discusses the majority of bridges in the U.S. consist of steel or concrete beams with a concrete deck. The primary cause of damaging fire events for these bridge types is vehicle crashes. Fires that fully involve the cargo of tanker and full...
Heavy goods vehicle trucks are the subset of crash events that cause serious damage or bridge collapse. Smaller vehicles, such as buses, empty trucks, and cars are much less likely to cause bridge damage. Other damaging events, such as rail car fires, construction fires, and fires involving flammable materials underneath bridges have also occurred but these are less common than crash events. This project looked at a probability based approach to assess risk but this proved to be elusive due to limitations of existing data. The probability of vehicle crashes is not random and there are many site specific issues that need to be considered. Site specific features are also responsible for non-crash related fire events (such as wild land fires). The overall operating situation must be considered for bridges on a case-by-case basis to evaluate risk. Overall, the probability of occurrence for damaging bridge fires is very low.

The NCHRP 12-85 project performed a literature review on factors affecting bridge response during fire and collected a database of case study information to better understand fire risk. Relevant databases were studied to assess fire risk from fire department reports and vehicle crash statistics. The NCHRP 12-85 project performed a series of fire simulation studies on a "typical" grade separation structure to provide a better understanding of how fire causes bridge damage. A state-of-the-art modeling methodology was developed that coupled a fire dynamics model, a thermal analysis model, and a structural response model to provide a complete simulation of realistic fire events under a bridge. This methodology was benchmarked through analyzing fire tests available in the literature.

Fuel source size: The NCHRP 12-85 Project suggests the Bus and 1/2-HGV fires did not cause any permanent bridge deflection for any of the fire locations. The tanker truck fire caused large permanent deflections at all fire locations evaluated in the study with complete collapse occurring when the tanker truck was at Location A. The HGV caused about 4 in. permanent deflection with the fire at Location A. For a "typical" girder type structure, it can be concluded that fully involved tanker fires are likely to cause permanent deflection for many fire locations. Fully developed HGV fires may cause some permanent deflection depending on conditions. Busses and 1/2-HGV fires are not likely to cause permanent deflection. This information should not be considered absolute since there are many variables involved in a given fire event. However, this serves as a guideline to isolate the fire events with the highest potential to cause bridge collapse and/or loss of service.

Fire duration: The NCHRP 12-85 project further suggests fire duration is heavily dependent on the fire size. In the hydrocarbon fires the bridge elements heat up faster, remain at an elevated temperature longer, and cool rapidly due to the larger bridge-ambient temperature difference. Discounting bearing and substructure damage, there are two effects that determine vertical deflection of the superstructure, high temperature plastic deformation and long term shifting or gradual movement of the structural members. The former is relatively insensitive to fire duration once thermal equilibrium is reached during the fire event. Under a sustained fire event of constant magnitude, thermal equilibrium will be reached where the material temperatures become relatively constant. Steel members will reach thermal equilibrium much faster than concrete members due to the differences in thermal properties between the two materials. The shifting or gradual movement of structural members, on the other hand, is highly influenced by fire duration. Members that are at thermal equilibrium will continue to slowly deform if they are under sustained stress. In redundant structural systems, shifting or gradual movement deformation may be limited by load shedding effects to other structural members. Fire duration is a primary factor affecting shifting or movement of structural member deformation but the structural system effects also need to be considered. The duration of fuel tanker fires is dependent on the leakage rate of fuel. Slower leaks may produce longer burning fire events with lower intensity. Likewise, the duration and intensity may vary for other types of vehicle fires. As an example of the effect of fire duration, the trash fire under the I-78 Bridge in Newark, NJ, burned for about 24 hours and caused about 9 in. of permanent deflection of the structure. This deflection can be attributed to shifting or movement of the structural member and a shorter duration fire of the same intensity may not have caused any permanent deflection.
Limited fire test data and time-temperature curves for highway bridge fire events are available. For hydrocarbon tanker truck fires a 45-minute duration fire event is recommended to simulate conditions experienced at the I-65 Birmingham Bridge Fire in Birmingham, Alabama. The Birmingham bridge fire event occurred on January 5, 2002 when the driver of a fuel tanker truck swerved to avoid a merging car while traveling on the I-59 ramp as it converges with I-65 South. The tanker truck collided with the pier of the I-65 overpass at the I-20, I-59 and I-65 interchange. The fire event consumed 9,900 gallons of diesel fuel and lasted approximately 45 minutes.

A second source of bridge fire event assessment is available in a graduate level thesis prepared by Michael Davidson from Western Kentucky University (2012) titled, *Assessment of Passive Fire Protection on Steel-Girder Bridges*. This document suggests fire-induced bridge collapses are perpetuated by the general lack of installed fire protection systems. The study indicates new materials and applications are needed to mitigate structural damage that can be caused to civil infrastructure by severe fires. Accordingly, the objective of this study is to further the development of new fire protection applications in transportation structures. Specifically, the investigation centers on the development of new applications in passive fire protection materials, within the context of shielding steel-girder bridges against severe fire effects. A steel-girder bridge has been selected for study, and a high-resolution finite element model has been formed based on the corresponding bridge structural drawings. Temperature-dependent structural material properties and thermal properties have been synthesized and incorporated into the model. A representative fire scenario has been formed (in part) based on a recent fire incident that occurred at the selected bridge site. The fire scenario also incorporates the characteristics of a fully loaded gasoline tank truck fire, where a means of incorporating the severe fire into the finite element model (as thermal loading) has been identified and enacted.

A.6.4  Fire protection strategies may include any of the following or combinations of the following based on recommendations following an engineering analysis including fire simulation calculations.

1. Strategies to minimize vehicle crash risk
2. Passive fire protection products
3. Physical separation (horizontally and vertically)
4. Active fire suppression systems
5. Control of operational situations around the structure, such as drainage control

Passive fire protection is the application of a physical barrier onto the structural element that reduces the temperature rise of the structural elements during fire exposure. Passive fire protection products are approved based on the exposure type and duration. A listing of approved passive fire protection products are provided in the UL Directory (2006). These listings include required application/attachment of the product as well as required thickness. An overview of these products, information on the exposure ratings, and potential application to bridges is provided below.

The first consideration in passive fire protection product selection is the fire exposure, which is defined based on a time-temperature basis. In the U.S., the ASTM E119 and UL 1709 fire exposure curves are most commonly used. The E119 curve is less severe compared to the UL 1709 fire exposure curve that better represents hydrocarbon fuel fires. The UL directory contains a variety of products from spray on fire resistive coatings, intumescent mats, fibrous insulation, and high temperature board products. The majority of these product listings are for building application; therefore, all products may not be appropriate for application onto structures exposed to outside weather conditions as is the case with bridges. The UL directory does contain products that will be sufficiently durable and prevent temperature rise of bridge structural elements exposed to tanker fires. These products will be
expensive, require maintenance, and limit surface inspection of the material they are applied onto.

Passive fire protection can reduce the thermal exposure onto the bridge. The decision on whether passive fire protection is needed must be determined by the AHJ. In the assessment of a bridge, the decision to include passive protection should be based on life safety, implications of loss of bridge service, and damage/replacement cost. Life safety is the primary reason for including passive fire protection in other structures. Based on results from previous bridges, there has not been a life safety issue for people not involved in the accident that typically produces the fire. If life safety is an issue, then appropriate design features must be invokes to allow people sufficient time to egress off the bridge to a point of safety. Loss of service due to bridge collapse has been the most significant issue. If the bridge is critical and there is a life safety issue, then an engineering assessment should be performed to determine whether additional protection is needed. From the analysis conducted in previous research, it is evident that bridge geometry and clearance can dramatically influence the potential for bridge collapse.

M.2 Informational References

Davidson, Michael, Western Kentucky University:  *Assessment of Passive Fire Protection on Steel-Girder Bridges*, December 1, 2012


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Committee Statement

Committee Statement: This section as written in the 2014 standard indicates that the provisions included in Chapter 6 are exempt if the bridge length is less than 1,000 feet. The risks from fire equally exist and endanger the structure when the bridge length is less than 1,000 feet. The following is a proposed revision to 6.2.1 through 6.3.4.
Committee Input No. 64-NFPA 502-2014 [ New Section after A.12.7 ]

A.12.8.6
In tunnels greater than 300 m in length, wayfinding lighting should be provided to aid motorists during the evacuation of the tunnel. Wayfinding lighting is used to provide guidance to pedestrians and delineate an evacuation route to an emergency exit.

(1) Wayfinding lighting should be located below a 1 meter height from the roadway surface.

(2) The evacuation and egress lighting systems should be automatically initiated when there is a tunnel power supply failure or when the tunnel emergency systems are activated.

(3) The evacuation and egress lighting systems should be continuously available for operation in the event of an emergency.

(4) The wayfinding egress lighting system should be wired from emergency distribution panels in separate raceways.

Reference Standard
CIE Technical Report 193 Emergency Lighting in Road Tunnels

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Committee Statement
Committee Statement: During a fire event smoke may be distributed throughout the tunnel and obscure the tunnel crown. Existing emergency lighting is typically located at a high soffit level, where the luminaires may be obscured by smoke. Emergency lighting at lower level and emergency escape routes should be considered.
Committee Input No. 34-NFPA 502-2014 [ New Section after D.1 ]

See attached word Document.

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Committee Statement

Committee Statement: This information would be inserted in Annex D.1 after Figure D.1

Based on theoretical and experimental data KI values can fall within a range when the for HRR is lower than or equal to 100 MW. Using the proposed KI values to determine critical velocity rather than the constant of 0.606 yield results that are more in line with recent research results.
Committee Input to add to Annex D1 under figure D.1:

Current research has revealed that the critical velocity equation found in Annex D has a range of applicability when a constant value of K_I is used. This range, based on a K_I correction factor of 0.606, renders the best results for fire heat release rates between values of 100 – 300 MW. At values less than a 100 MW these equations predict values that are lower than the critical velocity.

Between 5 MW – 100 MW the K_I value in equation D.1 varies significantly and a single constant value should therefore not be used. The following table D.1 provides guidance to the proper selection of the K_I value. These values are based on full scale and model scale test results, see reference for more information.

Table D1 A range of K_I value that apply for HRRs lower than or equal to 100 MW.

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<td>&gt;100</td>
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<tr>
<td>90</td>
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<tr>
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*The values are derived from theoretical and experimental data.

Reference:

### Annex M  Tunnel Automatic Fire Detection

*This annex is not part of the requirements of this NFPA document but is included for informational purposes only*

#### M.1 General

The purpose of this annex is to provide information on uses of Tunnel Automatic Fire Detection (TAFD), types of automatic tunnel fire detection systems, and limited pros and cons of types of TAFD.

Automatic Tunnel Fire Detection is a critical portion of ensuring minimum life safety is maintained as the accurate identification of the location and early detection of the fire is necessary before incident actions are initiated. The ATFD can initiate automatic system responses to a fire.

Time is of the essence since the early detection of the fire can be used to initiate not only water based fixed fire suppression system(s) (which can interrupt fire growth rate), but start the ventilation and other life safety systems.

Most fire detection systems create an electric signal at the point of detection that is sent to a fire alarm control panel which in turn notifies the operator, the tunnel control system(s), or both. The fire detection signal can have different thresholds at which the fire will be detected, i.e. a quantifiable measure such as a ‘rate of rise’ for a heat detection system. The TAFD can be set to create a pre alarm signal which allows notification to the Tunnel Operator of a possible problem before the system goes into full alarm. The fire threshold(s) can also initiate a full alarm without any pre alarm(s). Detection thresholds can be predetermined by the manufacturer, or be adjustable which provides the ability to detect fires at different points in the fire growth curve.

Use of fire detection in tunnels is a relatively new application with a few exceptions. The limited demand for tunnel detection and the difficult environmental challenges to install and operate a fire detection system in a tunnel has limited the number of listings by UL or other listing agencies. Therefore the number of listed devices approved for use in tunnels is limited. More devices will achieve UL listing status.

#### M.2 History

The first known use of an automatic TAFD system was in the Battery Street Tunnel in Seattle, USA, in 1954. This system used sealed copper tubes arrayed to match the deluge sprinkler zones. Heat from a fire would expand the air in the tubes. The increased pressure in the tube would trip a deluge valve located in adjacent underground vaults. The deluge valve opened and filled the water based sprinkler system.

Japan has a long history of installing tunnel fire detection systems a does Australia.

#### M.3 Tunnel Automatic Fire Detection Methods

Fire can create different fire ‘signatures’ that can be identified by various forms of detection. Each signature can be detected and used to inform the tunnel operator, and the fire control system. However, there are pros and cons to the different types of detection. The reliability of these systems is steadily improving with more accuracy and fewer nuisance alarms.

#### M.2.1 Heat from the fire, e.g. Linear Heat, Spot Detection, Infrared Camera systems

Fires which create significant heat may be expected, however, smoldering fires can create smoke but very little heat. Low levels of heat make detection difficult by this type of detector. Linear heat detection uses wire or fiber optics to detect changes in heat along a continuous wire mounted on the ceiling of the tunnel. Camera based detection identifies the digital heat signature which is processed by a computer. If camera based detection is used, the heat signature may not be visible by a camera system as the heat signature is shielded from view by vehicles. Non fire heat signatures such as vehicle exhaust can be detected by the camera or other methods creating a nuisance alarm. The threshold for heat detection using a higher temperature may therefore be raised to reduce nuisance alarms. This will delay the detection.
M. 2. 2 Smoke Camera smoke signature. Very Early Smoke Detection Apparatus (VESDA) uses an aspirated system to draw in air from multiple locations in the tunnel. The air is measured to identify the presence of smoke. If smoke is present, this initiates a fire detection signal. Cameras can be used to identify a smoke digital signature which is processed by a computer to verify the presence of smoke. The smoke signature can be obscured by vehicles resulting in a slower detection.

M. 2. 3 Flame e.g. flame signature (camera based) uses a digital signature which is processed by a computer to identify a fire versus a bright light or other nuisance alarm source.

M. 2. 4 Combination methods can combine two or more detection systems to limit the nuisance alarms, provide greater accuracy and limit the negative impact of an obscured fire (cameras only).

M. 4. Examples of tunnel fire detection. To inform the tunnel industry of research and testing in this limited area, the following resources are provided.

M. 4. 1 International Road Tunnel Fire Detection Project, Fire Protection Research Council 2008

M. 4. 2 Washington DOT, Interstate 90 Mt Baker Ridge and Mercer Island tunnels

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**Committee Statement**

Committee Statement: This proposed Annex M provides information on uses of Tunnel Automatic Fire Detection (TAFD), types of automatic tunnel fire detection systems, and limited pros and cons of types of TAFD.