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An American National Standard

Standard Specification for Transportation Tunnel Structural Components and Passive Fire Protection Systems[1]

This standard is issued under the fixed designation E3134; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

INTRODUCTION

Fire poses a serious threat to the structural stability of tunnels as shown by real fires in tunnels over the last decade. The damage is a serious threat to life safety and results in costly repairs and lost service time. The damage is mitigated with heat-resistant concrete and passive fire-resistive materials and systems. The result is limited spalling of concrete, limited structural damage of the concrete via cracks to the cold zone, and limited temperature increases of the reinforcing steel. Further, the fire-resistive methods employed are also optionally evaluated against common environmental exposures, which could adversely affect the performance or fire-resistance rating.

1. Scope

1.1 This specification is applicable to the fire resistance of concrete tunnel linings, fire-resistive materials, and structural tunnel members.

1.2 Concrete mix design, tunnel linings, and passive fire protection methods are specific to each tunnel project. Therefore results of the spalling test are only valid for the specific materials and systems employed during each test, notwithstanding maximum and minimum limitations.

1.3 Tunnels are potentially exposed to ground water, even those passing through elevated terrain, such as mountains, road salt, and maintenance surface washing. Consideration shall be given to potential adverse effects that result, such as material degradation due to these exposures.

1.4 Movement joints shall be considered and their impact on the overall fire resistance shall be assessed by testing. Tests shall be conducted as a system.

1.5 This specification does not address mechanical attachment methods for equipment due to the vast variety of possible methods and loads. However, consideration shall be given to methods that appreciably affect the concrete temperature during the heating conditions. Consideration shall be given to a second test conducted with the attachment to evaluate the effect. The attachment test shall include the largest diameter anchor, the deepest installed anchor, and the largest load applied to the anchor. This requirement results in a single anchor being tested or multiple anchors being tested. If multiple anchors are required to be tested, then each shall be tested under its maximum load.

1.6 This specification requires testing of both horizontal and vertical orientations. For fire-resistive materials, it is generally accepted that the horizontal orientation represents the worst case test scenario.

1.7 The values stated in SI units are to be regarded as standard. The values given in parentheses are mathematical conversions to inch-pound units that are provided for information only and are not considered standard.

1.8 *This standard is used to measure and describe the response of materials, products, or assemblies to heat and flame under controlled conditions, but does not, by itself, incorporate all factors required for fire hazard or fire risk assessment of the materials, products, or assemblies under actual fire conditions.*

1.9 *Fire testing is inherently hazardous. Adequate safeguards for personnel and property shall be employed in conducting these tests.*

1.10 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.11 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the*

[1] This specification is under the jurisdiction of ASTM Committee E05 on Fire Standards and is the direct responsibility of Subcommittee E05.11 on Fire Resistance.

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Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C109 Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens)

E84 Test Method for Surface Burning Characteristics of Building Materials

E119 Test Methods for Fire Tests of Building Construction and Materials

E176 Terminology of Fire Standards

E1966 Test Method for Fire-Resistive Joint Systems

G85 Practice for Modified Salt Spray (Fog) Testing

2.2 *Other Standard:*[3]

2008-Efectis-R0695 Fire testing procedure for concrete tunnel linings

3. Terminology

3.1 *Definitions*—For definitions of terms found in this specification, refer to Terminology E176.

4. Summary of Test Method

4.1 Different fire protection approaches are chosen in the design and construction of tunnels. The approaches addressed in this specification are limited to concrete mix design and fire-resistive materials, and the potential impact of environmental exposures (optional). A minimum of one fire test is required for each assembly, configuration, and orientation. For cases where the concrete mix design is intended to address the fire load independent of fire-resistive materials, the Spalling Test in accordance with 9.1 is applicable. For cases where standard or general concrete design mix is intended and protected by fire-resistive materials, the Fire-Resistive Material Test is applicable. For cases where both the concrete design mix and fire-resistive materials are combined to address the fire load, both test criteria are applicable but can be accomplished with one fire test for each assembly, configuration, and orientation.

4.1.1 *Surface Burning Test:*

4.1.1.1 Flame Spread Index (FSI) and Smoke Developed Index (SDI) in accordance with Test Method E84 are provided for fire-resistive materials.

4.1.2 *Environmental Tests (Optional):*

4.1.2.1 Ground Water Test is a means to assess the effect of water and moisture on concrete tunnel lining and fire-resistive materials.

4.1.2.2 Road Salt Test assesses the effect of salt on concrete tunnel lining and fire-resistive materials.

4.1.2.3 Tunnel Interior Surface Washing assesses the effects of repeated washing on concrete tunnel lining and fire-resistive materials.

4.1.2.4 *Spalling Test*—The Spalling Test is intended to assess the spalling behavior of concrete mix designs specific to tunnel project specification. The test assesses the reinforcing steel by means of temperature and temperature of other critical locations, such as post tension sleeves.

4.1.2.5 *Fire-Resistive Material Test*—The Fire-Resistive Material Test is intended for materials whose purpose is to protect the concrete by limiting the temperature at the interface with the concrete and limiting reinforcing steel temperatures within the concrete.

4.1.3 *Fire-Resistive Joint Test*—When movement joints are used as part of the tunnel construction, they shall be assessed for fire resistance and the ability to undergo movement without reducing the fire rating.

5. Significance and Use

5.1 The test methods described in this specification are used to determine the performance of tunnel construction elements with respect to exposure to a standard time-temperature fire test. The performance of the elements is dependent upon the specific assembly of materials tested.

5.2 The test exposes a specimen to the selected fire exposure, as described in this specification, controlled to achieve specified temperatures throughout a specified time period.

5.3 The test standard provides for the following:

5.3.1 *Flame Spread*—Comparative measurements of flame spread and smoke developed in accordance with Test Method E84.

5.3.2 *Environmental Considerations*—Potential effects on the fire resistance from environmental conditions expected within a transportation tunnel.

5.3.3 *Spalling*—Susceptibility of concrete design mixes to spalling when exposed to the fire exposure, as described in this specification.

5.3.4 *Transmission of Heat*—The ability to limit temperatures at critical locations such as reinforcing steel and interface of fire-resistive materials and concrete.

5.3.5 *Fire-Resistive Joints*—The ability to maintain fire resistance continuity when the assembly requires a joint to mitigate the effects of movement.

5.4 The test standard does not provide the following:

5.4.1 Evaluation of active fire protection methods or systems or other techniques not appropriate for evaluation by this specification.

5.4.2 Information as to performance of specimens constructed with components or lengths other than those tested.

5.4.3 Evaluation of the degree by which the specimen contributes to the fire hazard by generation of smoke, toxic gases, or other products of combustion.

5.4.4 Measurement of the degree of control or limitation of the passage of smoke or products of combustion through the specimen.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from efectis nederland, P.O. Box 554, 2665 ZN Bleiswijk, Brandpuntlaan Zuid 16, 2665 NZ Bleiswijk, The Netherlands, http://efectis.com/wp-content/uploads/2016/07/RWSProcedureFireProtectionforTunnels.pdf.

6. Flame Spread

6.1 Fire-resistive materials shall be tested in accordance with Test Method E84. The FSI shall be ≤25 and SDI ≤50.

7. Environmental Tests

7.1 Environmental tests shall be conducted when the test sponsor, design professional, or authority having jurisdiction has a concern about the impact on fire resistance from the presence of water, road salt, or repeated surface washing, or combinations thereof. The environmental tests are performed in advance of the fire testing to evaluate environmental impact. Included are ground water test, road salt test, and tunnel interior surface washing. For more details on the environmental tests, see Appendix X1.

8. Control of Fire Tests for Fire Resistive Materials

8.1 *Time-Temperature Curve:*

8.1.1 The fire exposure shall be controlled to conform to the modified Rijkswaterstaat (RWS) curve, taken from 2008-Efectis-R0695, presented in Tables 1 and 2, and as shown in Fig. 1.

8.1.2 As an option, an alternate time-temperature curve is presented in Annex A1. The alternative time-temperature curve presented incorporates the highest temperatures of the various furnace fire exposures known at the time this document was written. The intent is to provide a worst case test to allow for multiple approvals from one test.

8.1.3 The samples shall undergo a cool down period by decreasing the furnace temperature by 10 °C (18 °F) per minute for 100 min, see Table 2.

8.2 *Furnace Temperature:*

8.2.1 The temperature fixed by the curve shall be the average temperature obtained from the readings of thermocouples symmetrically distributed within the test furnace to show the temperature near all parts of the assembly. Use a minimum of three thermocouples, with no fewer than five thermocouples per 9.3 m^2 (100 ft^2) of exposed floor surface, and no fewer than nine thermocouples per 9.3 m^2 (100 ft^2) of exposed wall surface.

8.2.2 The furnace thermocouples shall be Type B, platinum-rhodium, 0.81 mm (0.032-in.) wire, exposed junction thermocouples. One conductor contains 30 % rhodium and the other conductor contains 6 % rhodium.

TABLE 1 Tunnel Fire Test Time-Temperature Curve for Control of Fire Tests

Time (min)	Temperature [°C (°F)]
0	20 (68)
3	891 (1635)
5	1141 (2085)
10	1199 (2190)
30	1299 (2370)
60	1349 (2460)
90	1299 (2370)
≥120	1199 (2190)

TABLE 2 Tunnel Fire Test Cool Down, Time Interval Versus Temperature Decrease

Added Time (min) from Time of Desired Rating Period	Furnace Temperature [°C (°F)] Decrease from Time of Desired Rating Period
+10	–100 (–180)
+20	–200 (–360)
+30	–300 (–540)
+40	–400 (–720)
+50	–500 (–900)
+60	–600 (–1080)
+70	–700 (–1260)
+80	–800 (–1440)
+90	–900 (–1620)
+100	–1000 (–1800)

8.2.3 For samples in the horizontal orientation, place the junction of the thermocouple 305 mm (12.0 in.) away from the exposed face of the sample.

8.2.4 For samples in the vertical orientation, place the junction of the thermocouple 152 mm (6.0 in.) away from the exposed face of the sample.

8.2.5 Read and record the temperature at intervals not exceeding 1 min.

8.2.6 The accuracy of the furnace control shall be such that the area under the temperature-time curve, obtained by averaging the results from the furnace thermocouple readings, is within 15 % of the corresponding area under the standard temperature-time curve presented in Tables 1 and 2, and as shown in Fig. 1, for the time period between 5 and 10 min, 10 % for the time period between 10 and 30 min and 5 % from 30 min to the end of the test.

NOTE 1—The spalling of concrete will expose new, cold concrete surfaces that will increase the need for energy input in order to maintain furnace control within tolerance.

8.3 *Furnace Pressure:*

8.3.1 Measure the differential pressure between the exposed and unexposed surfaces of the test assembly. The pressure shall be measured using a tee-shaped probe, or a tube probe, as shown in Fig. 2, manufactured from stainless steel, or other suitable material.

8.3.2 Measure the pressure by means of a manometer or equivalent transducer. The manometer or transducer shall be capable of reading 2.5-Pa (0.01-in. H_2O) increments with a measurement precision of 1.25 Pa (0.005 in. H_2O).

8.3.3 *Horizontal Specimen*—The required differential pressure plane shall be located within the furnace 305 mm (12 in.) below the specimen.

8.3.4 *Vertical Specimen*—The required differential pressure plane shall be located within the furnace at the mid-height of the specimen.

8.3.5 Following the first 5 min of the test, the pressure shall be controlled at below 50 Pa (0.2 in. H_2O), then following the first 10 min, the pressure shall be controlled at 20 ± 4 Pa (0.08 ± 0.016 in. H_2O).

NOTE 2—It is recognized that the dynamic nature of the furnace limits the ability of pressure control within the furnace, so there is a greater tolerance for the first 10 min of startup. However, the goal is to achieve a stable pressure of 20 Pa as quickly as possible.