THE FIRE-RESISTANCE PERFORMANCE OF NEW AND LEGACY CONCRETE FIREPROOFING

Efectis

SPEAKER

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  - Fire resistance of concrete structures/tunnels
  - Protection of concrete structures
  - Fire modelling
  - Co-author/editor of Efectis-R0695:2020
    - Fire testing procedure for concrete tunnel linings and other tunnel components
  - Principal NFPA 502 committee
    - Standard for Road Tunnels, Bridges, and Other Limited Access Highways

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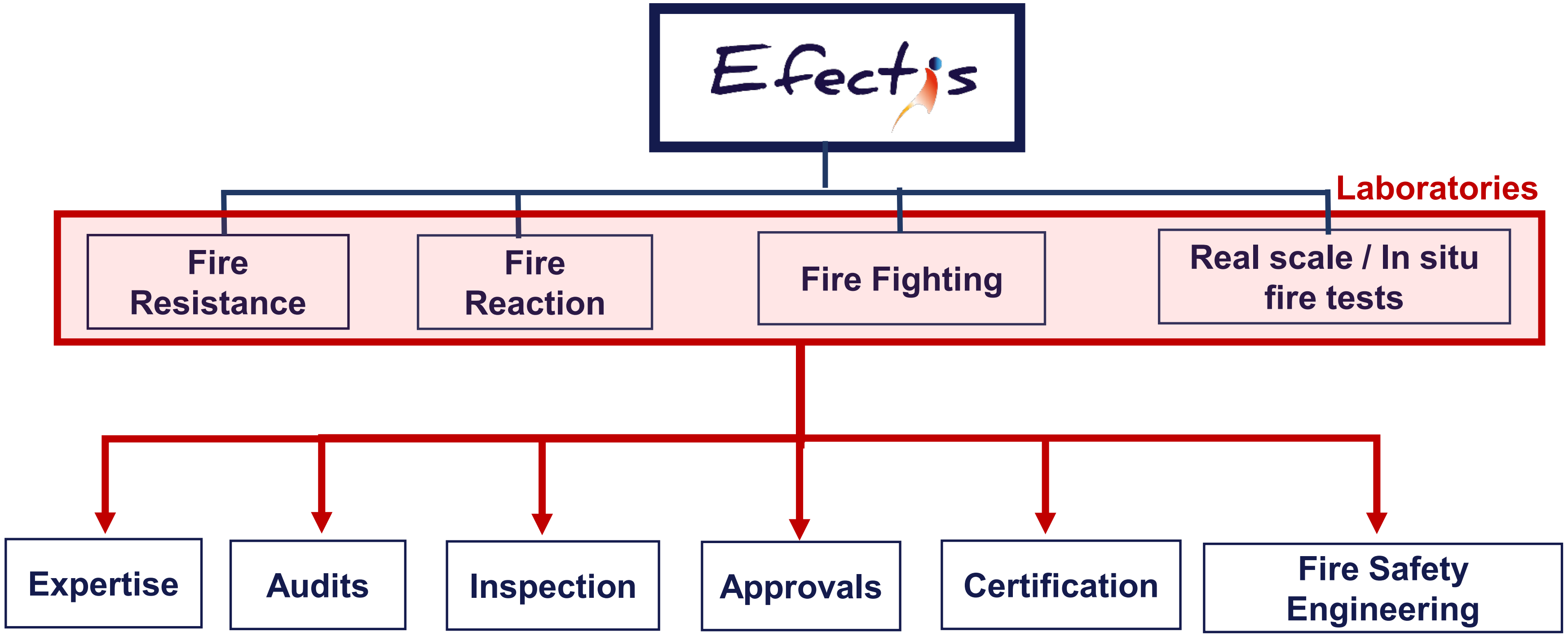
EFECTIS GROUP OVERVIEW



Efectis is a global player in the fire science and specializes in fire safety including testing, modeling, certification, education and inspection.

PFPNET TUNNELS TECHNICAL SUBCOMMITTEE (1)

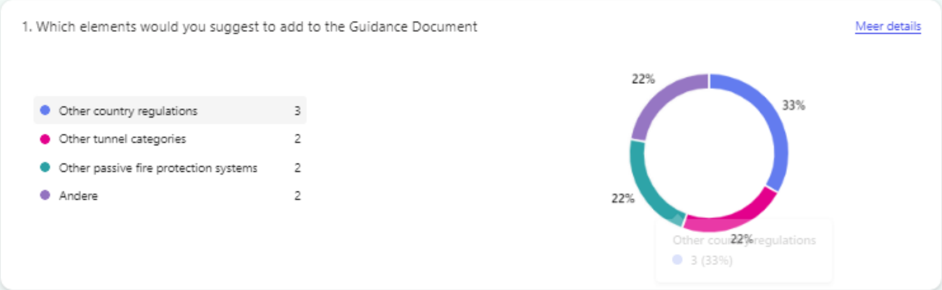
- Chair Kees Both of Etex/Promat

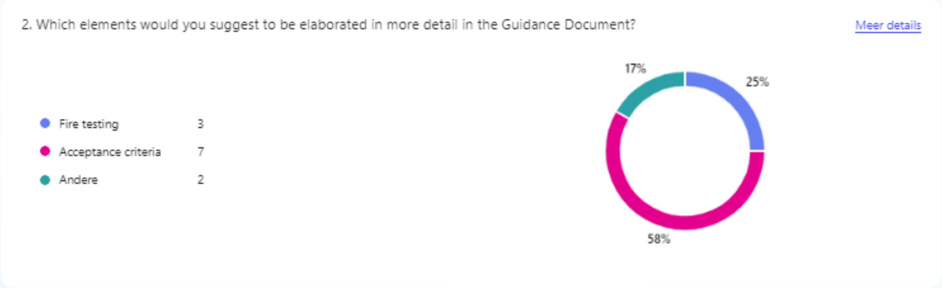
- Guidance on Structural Passive Fire Protection in Road Tunnels
  - Issued March 2024
  - Get a copy from Simon Thurlbeck

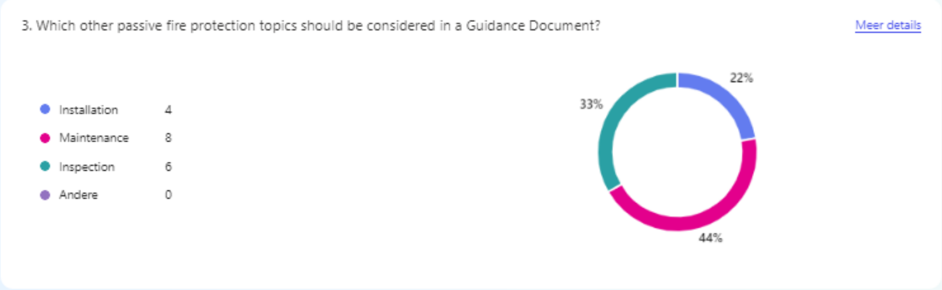
- PFPNet webinar - Fire Protection In Road Tunnels July 2024
  - Two Efectis speakers, Talal Fateh & Jos Bienefelt
  - Two sessions:
    - Morning session 44 attendees
    - Afternoon session 44 attendees

PFPNET TUNNELS TECHNICAL SUBCOMMITTEE (2)

- After the webinar a questionnaire was sent to the participants – 10 responses







THE FIRE RESISTANCE PERFORMANCE OF NEW AND LEGACY CONCRETE FIREPROOFING

Method for determining the required thickness of a passive fire protection system

Fire-resistance performance of new and legacy concrete fireproofing

→ In-situ fire-resistance testing with mobile furnace

TOPICS

Background on concrete structures at fire conditions

Requirements for tunnels

Thermal behavior of passive fire protection/concrete structure

Method for choosing thickness of passive fire protection

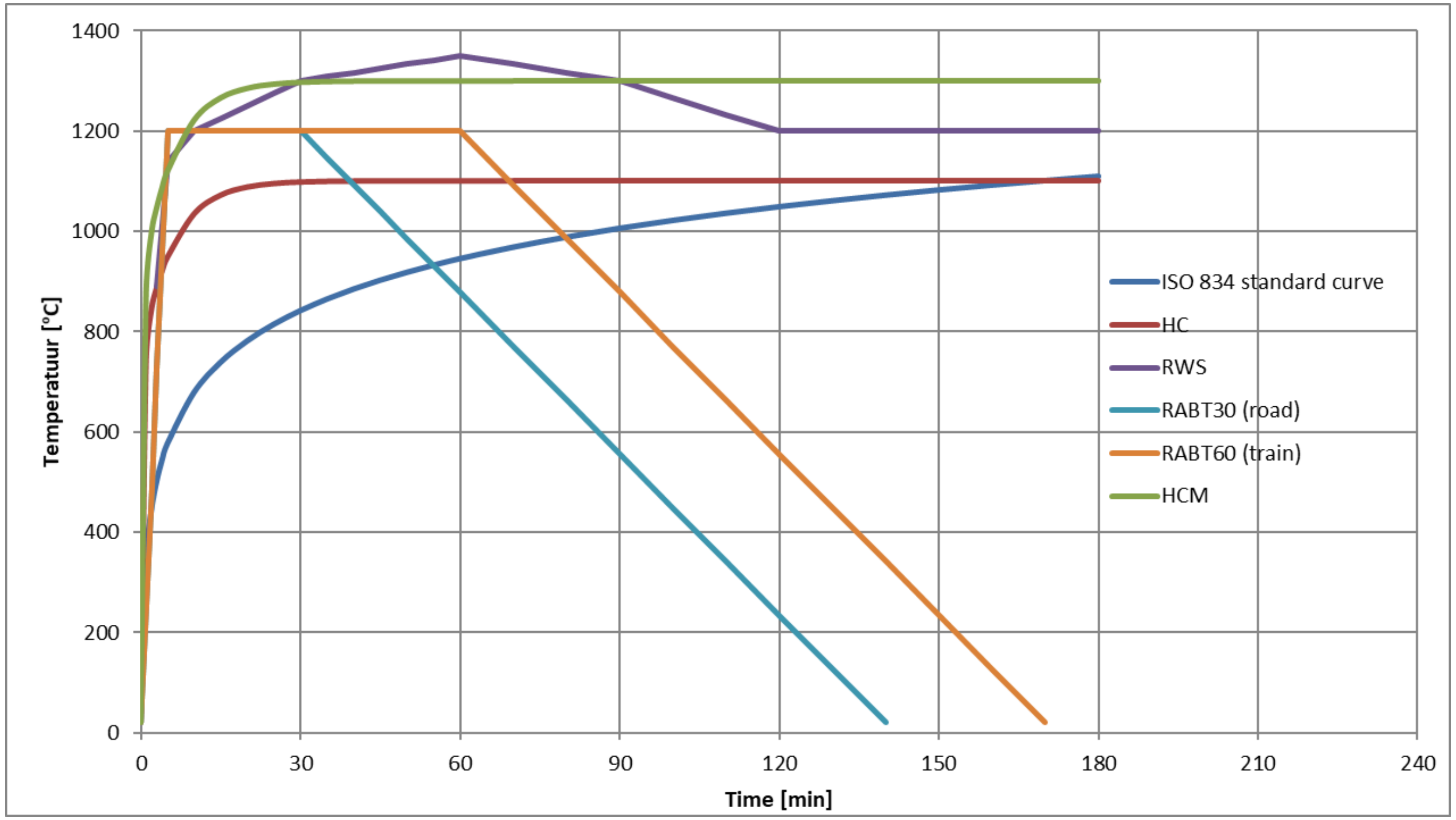
In-situ fire resistance testing

Q & A

CONCRETE STRUCTURES AT FIRE CONDITIONS (1)

Fire scenario

→ Common temperature-time fire curves for tunnels



Source: PFPNet Guidance on Structural Passive Fire Protection in Road Tunnels

CONCRETE STRUCTURES AT FIRE CONDITIONS (2)

In a general sense concrete has good properties when it comes to fire-resistance:

→ Concrete is non-combustible

→ Concrete has good insulating properties

→ No toxic fumes are emitted while heating

→ Concrete performs satisfactory for relatively long periods of time under fire conditions

Performance criteria are:

→ Load-bearing capacity

→ Resistance to flame penetration

→ Resistance to heat transfer

CONCRETE STRUCTURES AT FIRE CONDITIONS (3)

Concrete will get damaged during fire despite the good qualities it has. Depending on fire exposure the following will occur:

→ Thermal degradation

→ Fire-induced spalling

Especially fire-induced spalling may lead to premature structural failure of a tunnel structure

CONCRETE STRUCTURES AT FIRE CONDITIONS (4)

Fire-induced spalling

→ Sudden and often violent phenomenon at which lumps of concrete break loose of the structure

Fire-induced spalling is a complex phenomenon and dependent on a variety of factors:

Internal factors

→ Cement type

→ Aggregate size and type

→ Moisture content

→ Porosity and permeability

→ Geometry of the structure

External factors

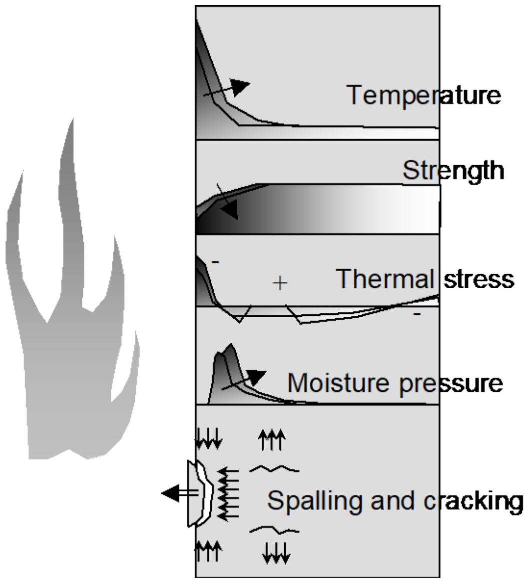
→ Compressive loading

→ Restrained thermal expansion

→ Heating and heating rate

Fire-induced spalling can quickly lead to a reduction of the cross-section of a structure and thus a reduction in strength

CONCRETE STRUCTURES AT FIRE CONDITIONS (5)



Spalling can occur in different forms, each of which is caused by a specific combination of the following mechanisms:

→ Pore pressure rises due to evaporating water when the temperature rises
→ Compression of the heated surface and tension in the cold concrete due to a thermal gradient in the cross section
→ Internal cracking due to difference in thermal expansion between aggregate and cement paste
→ Cracking due to difference in thermal expansion/deformation between concrete and reinforcement bars
→ Strength loss due to chemical transitions during heating

Source: PFPNet Guidance on Structural Passive Fire Protection in Road Tunnels

CONCRETE STRUCTURES AT FIRE CONDITIONS (6)

Although big strides have been made in the recent past in understanding fire-induced spalling, theoretical models, mathematical or physical have so far been unable to accurately predict spalling.

The most reliable way to determine the spalling behavior is through fire testing.

A method that gives useful information for PFP design will be discussed.

REQUIREMENTS FOR TUNNELS (1)

- (Progressive) collapse of tunnel structure is usually not allowed

  → limited or no fire-induced spalling is allowed

- Stricter requirements are usually set to aid in the repairability of the tunnel structure after fire

  → no fire-induced spalling is allowed

  → stricter requirements for the temperature development of the concrete/reinforcement

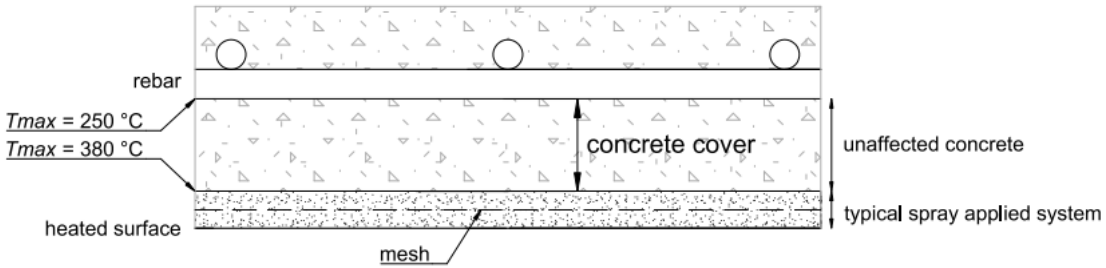
  → the stricter requirements can be met by using a passive fire protection system

REQUIREMENTS FOR TUNNELS (2)

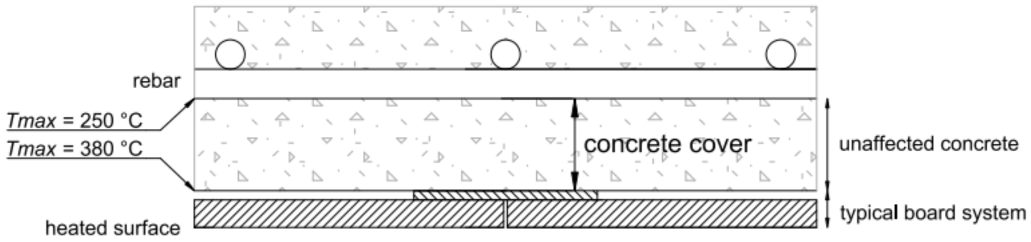
RECOMMENDED (NON-COMPULSARY) PERFORMANCE CRITERIA (CONTINUED)

Criteria for concrete with a fire protection system

Spray applied system



Board system



For concrete under compression with a fire protection system in a tunnel of major importance, the requirements are:

- T_{max} < 250 °C for steel reinforcement bearing internal forces of the construction. If steel reinforcement consists of prestressing steel the following requirements are applicable:
  - T_{max} < 150 °C for cold worked (cw) prestressing steel;
  - T_{max} < 75 °C for quenched and tempered (q & t) prestressing steel.
- T_{max} < 380 °C at the concrete surface;
- Spalling of concrete is not allowed.

Source: Efectis-R0695:2020

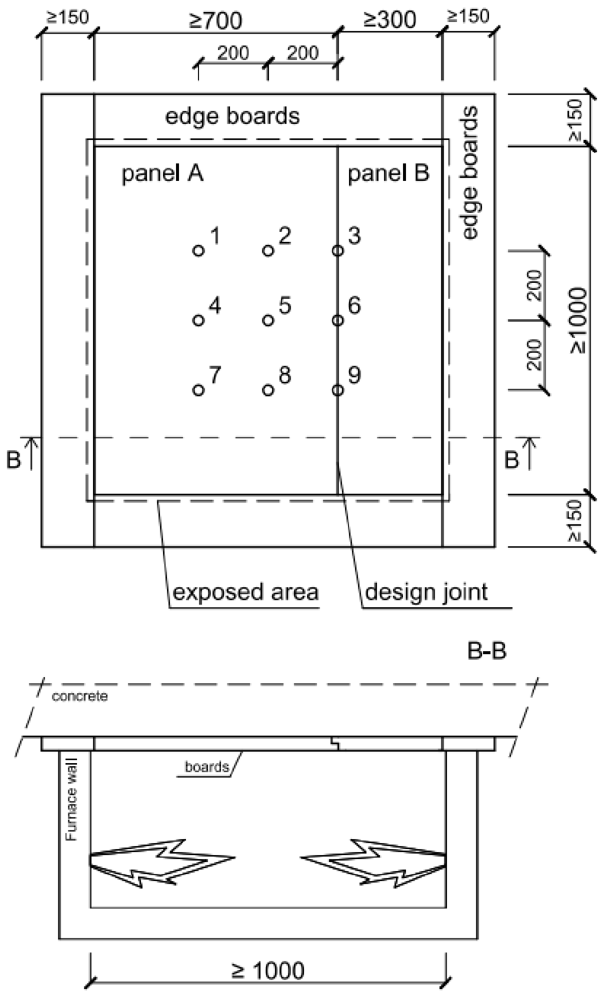
THERMAL BEHAVIOR OF PASSIVE FIRE PROTECTION/CONCRETE (1)

In tunnels mostly fire protection systems based on spray-applied mortar or fire-resistant boards are used.

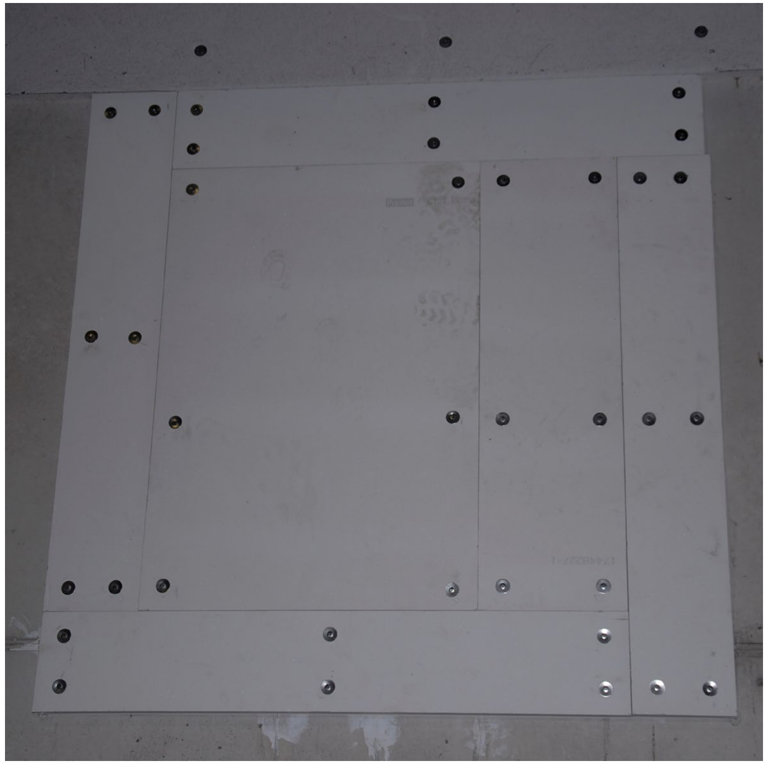
Qualitatively, these systems show the same thermal behavior at the concrete surface (interface).

For more information about the available fire protection systems please consult the PFPNet Guidance Document.

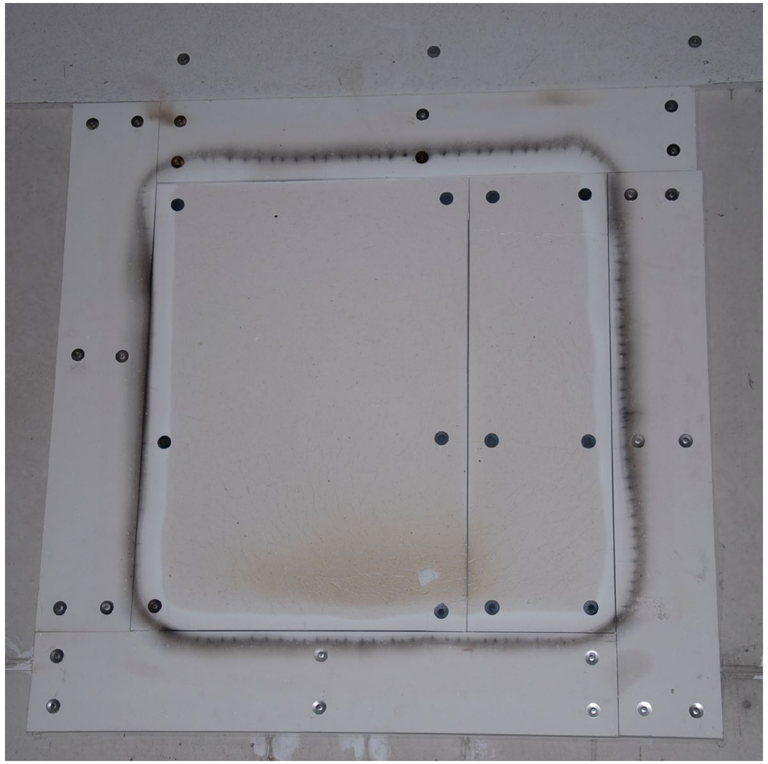
THERMAL BEHAVIOR OF PASSIVE FIRE PROTECTION/CONCRETE (2)



Source: Efectis-R0695:2020

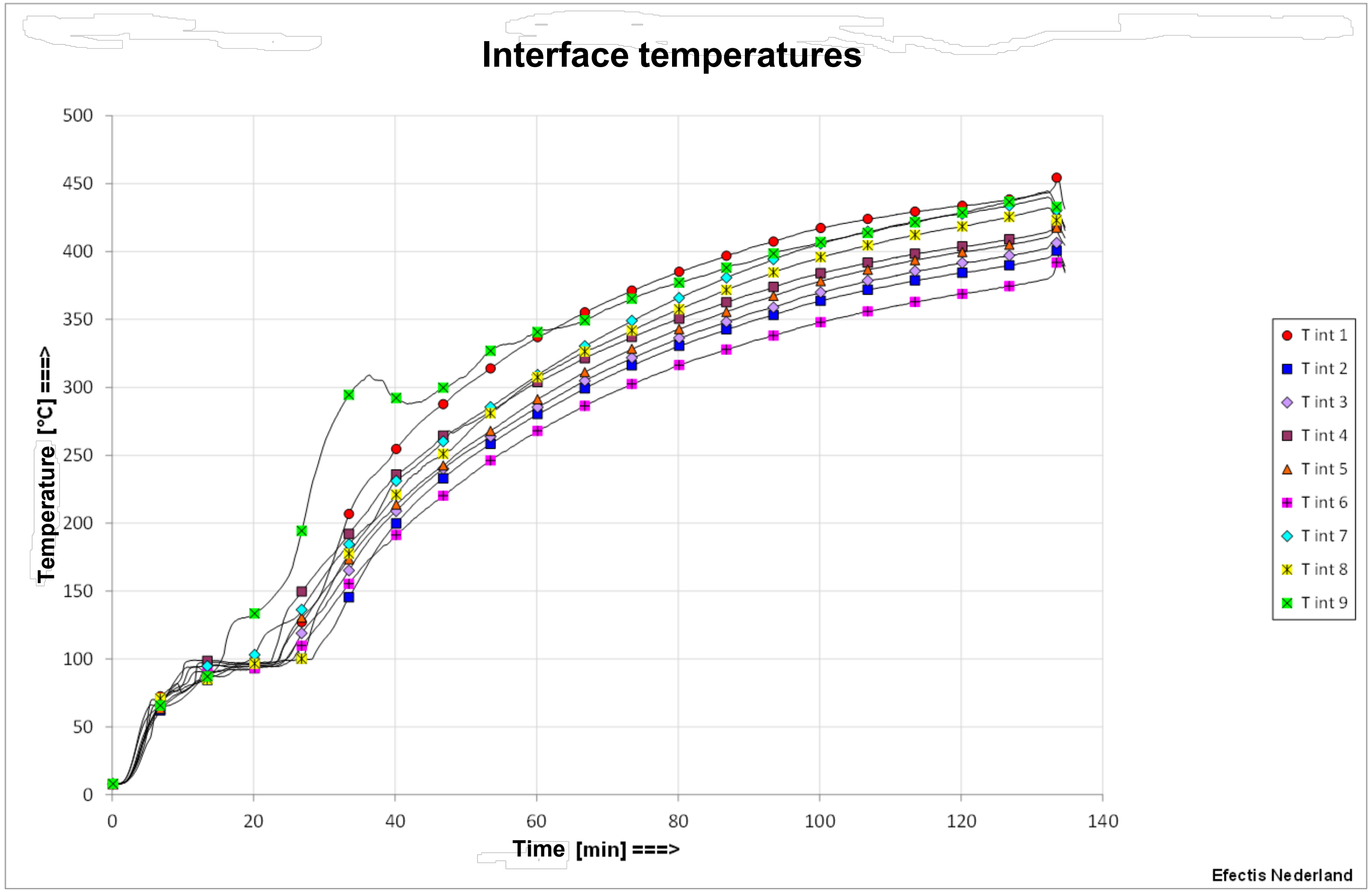


Before fire test

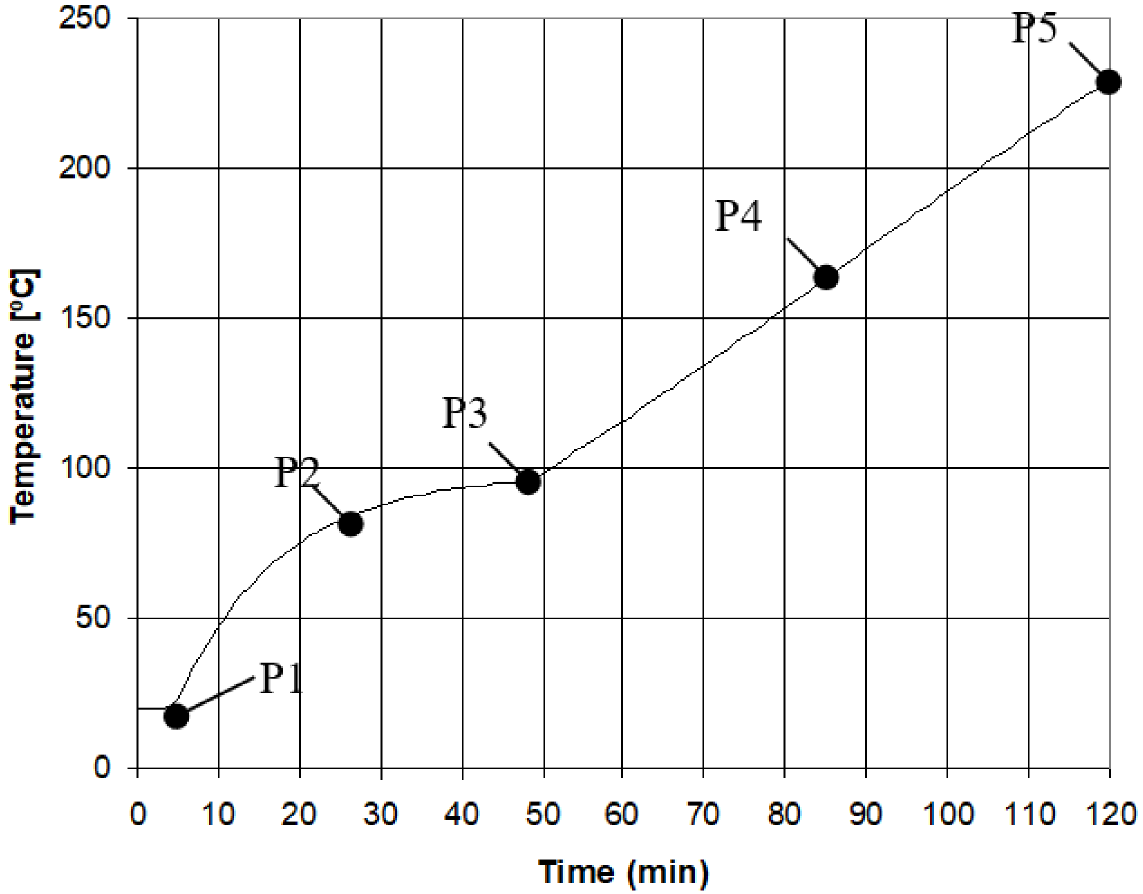


After fire test

THERMAL BEHAVIOR OF PASSIVE FIRE PROTECTION/CONCRETE (3)



THERMAL BEHAVIOR OF PASSIVE FIRE PROTECTION/CONCRETE (4)



THERMAL BEHAVIOR OF PASSIVE FIRE PROTECTION/CONCRETE (5)

Interface temperatures show quite a large spread

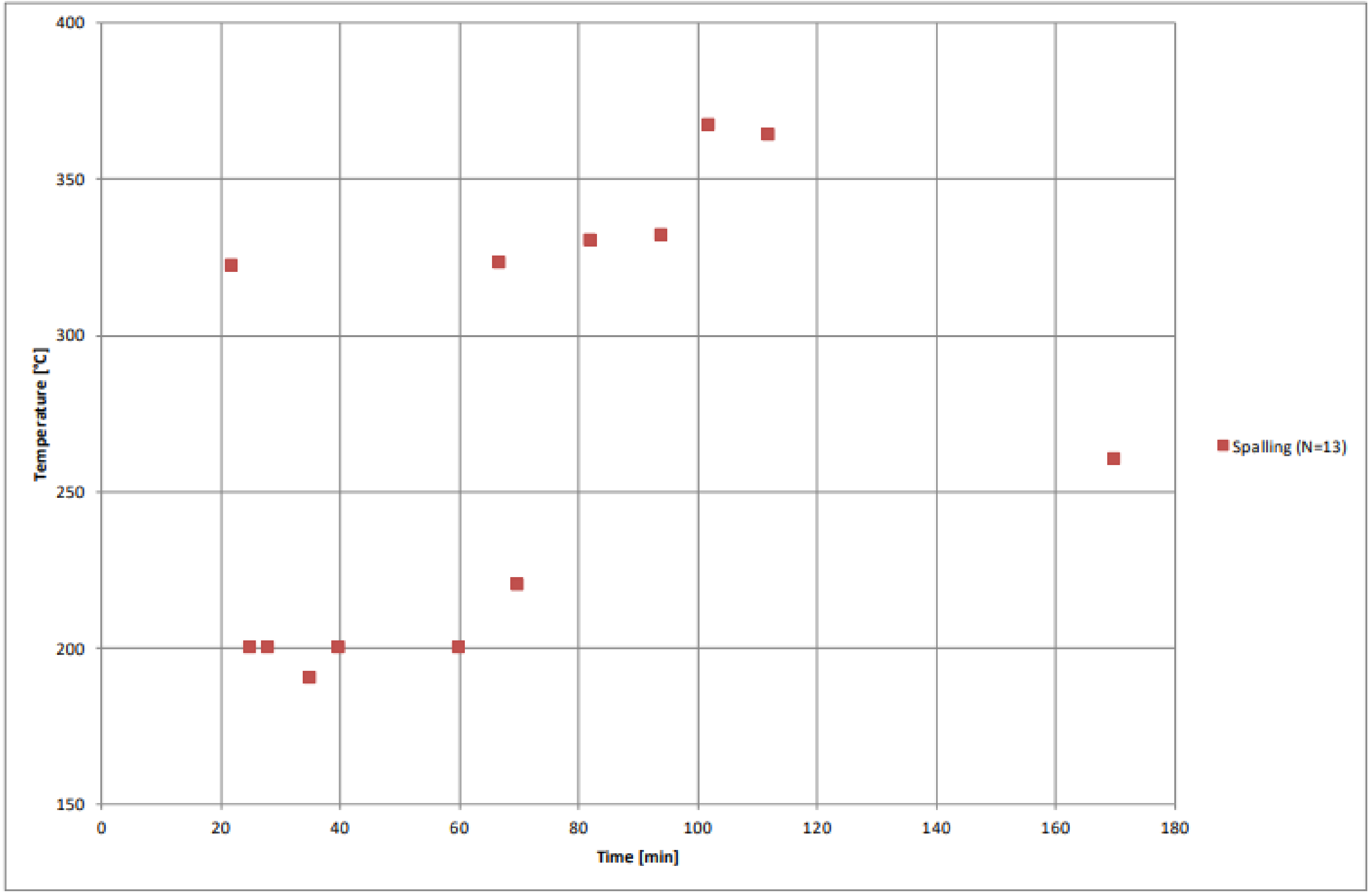
Not all thermocouples show the same behavior

For analyses purposes the following is determined:

→ Average temperature at a given time
→ Maximum temperature at a given time
→ A 95 % characteristic temperature based on Student's T-distribution

THERMAL BEHAVIOR OF PASSIVE FIRE PROTECTION/CONCRETE (6)

Temperatures at which spalling occurs (spalling temperature)



METHOD FOR CHOOSING THICKNESS OF PASSIVE FIRE PROTECTION (1)

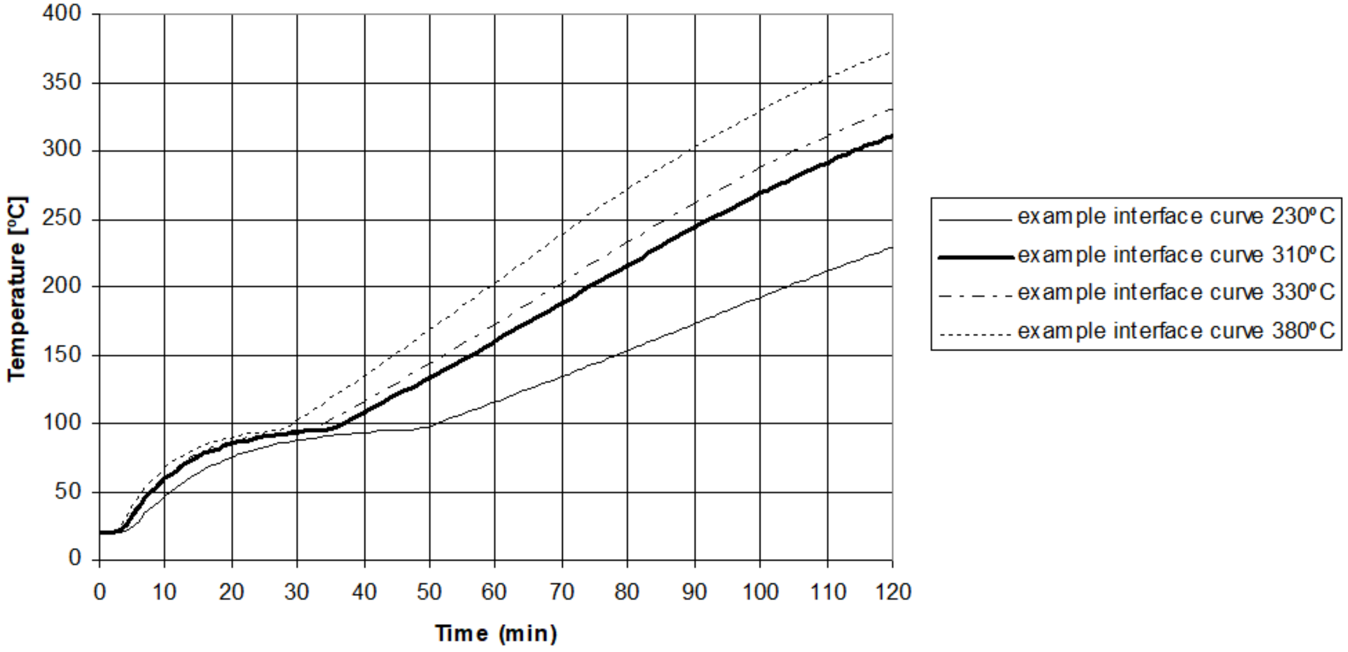
"dummy" fire-resistant board

→ Same type of board material used to protect the tunnel.

→ Underdimensioned for the application at hand.

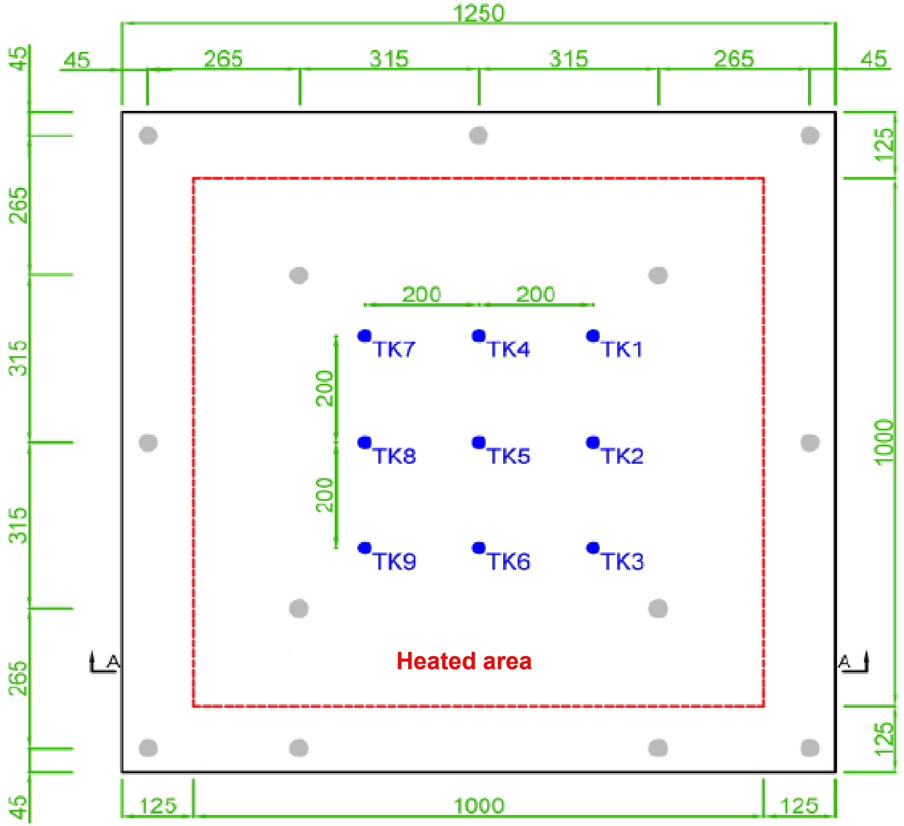
→ No joints in board.

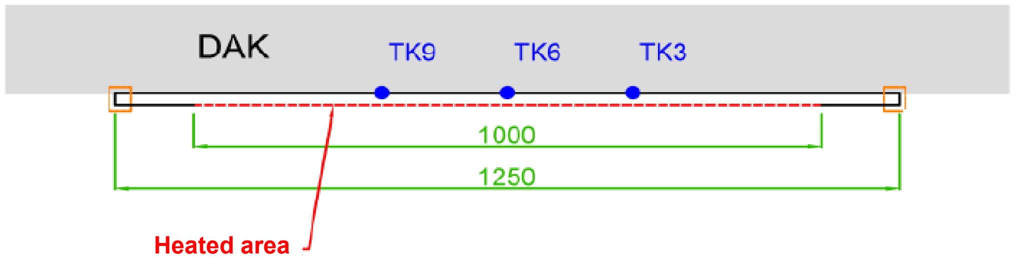
→ Goal is to induce spalling before the end of the required fire-resistance period.



METHOD FOR CHOOSING THICKNESS OF PASSIVE FIRE PROTECTION (2)

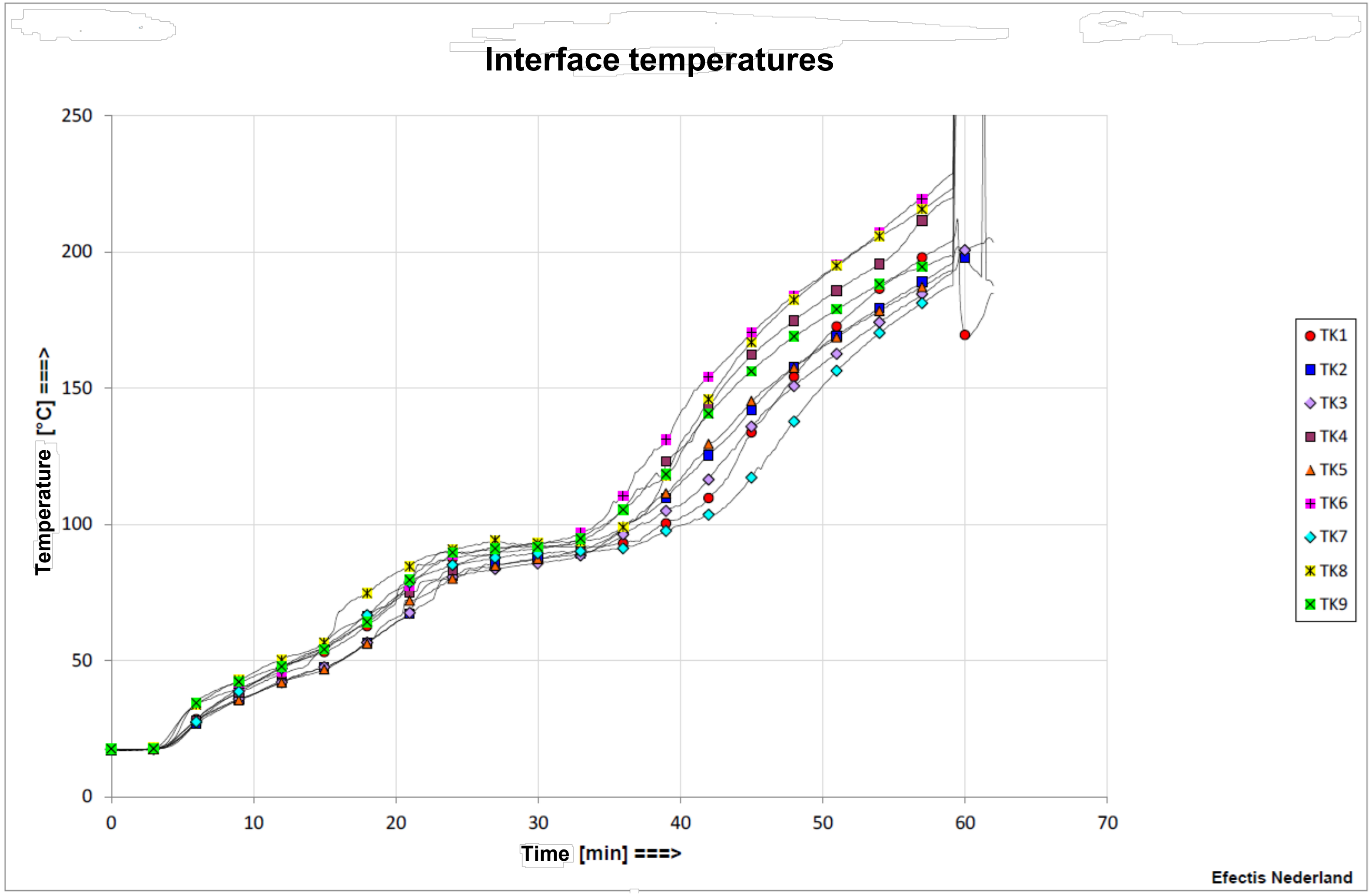
“dummy” board, nominal 20 mm thickness





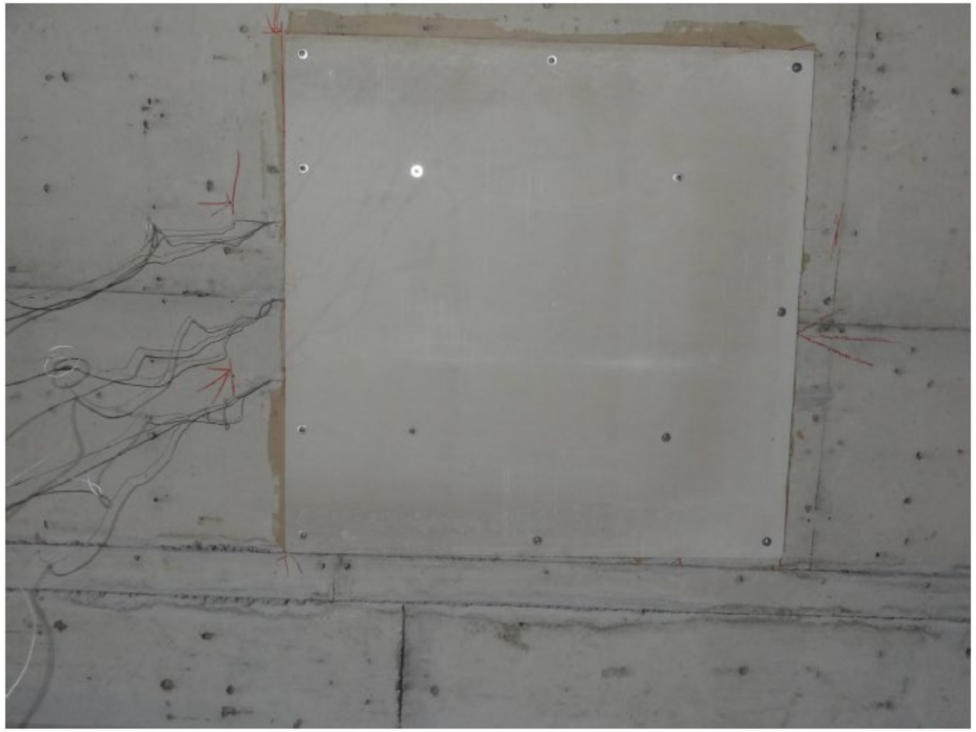
METHOD FOR CHOOSING THICKNESS OF PASSIVE FIRE PROTECTION (3)

Example 1

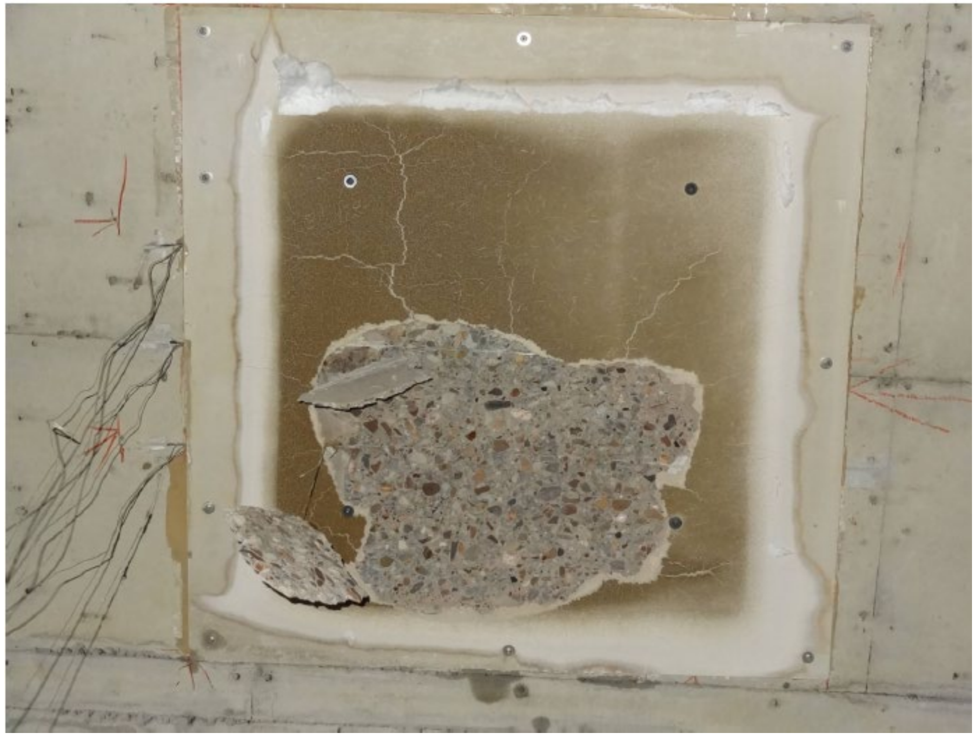


METHOD FOR CHOOSING THICKNESS OF PASSIVE FIRE PROTECTION (4)

Example 1



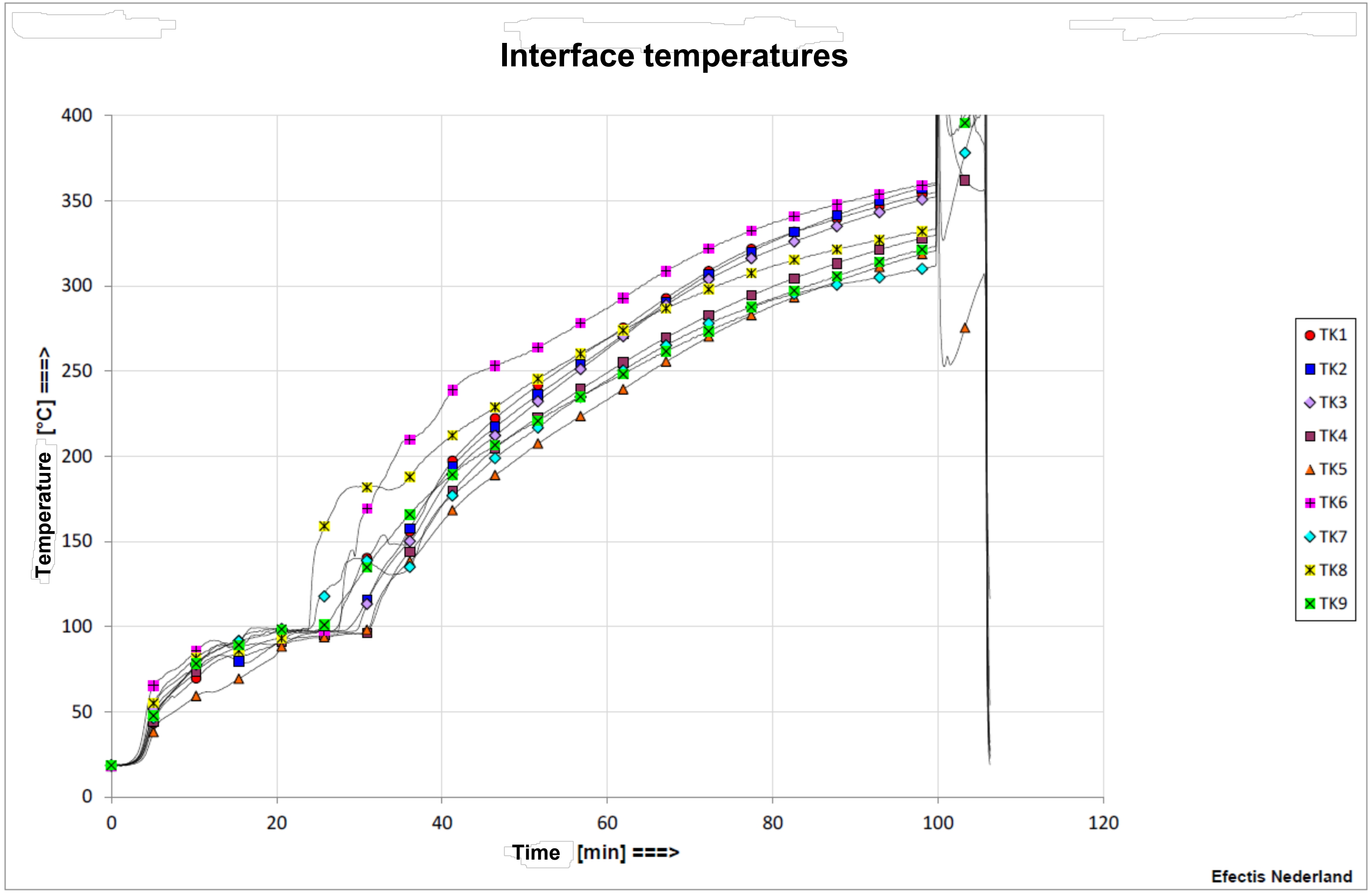
Before fire test



After fire test

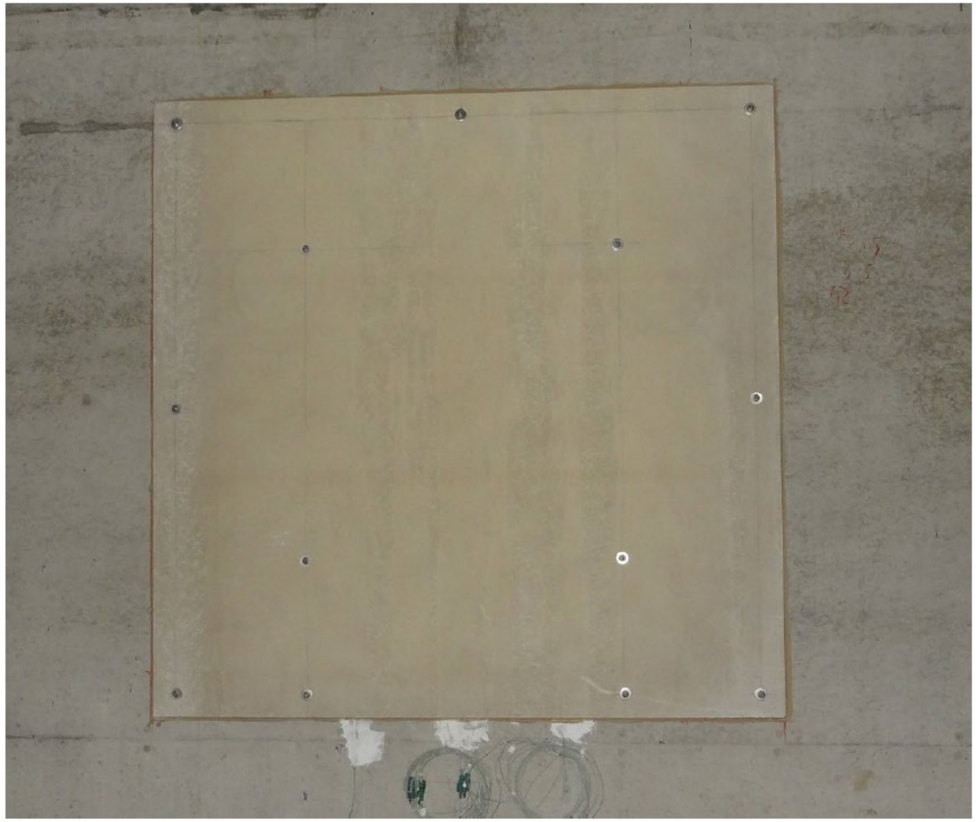
METHOD FOR CHOOSING THICKNESS OF PASSIVE FIRE PROTECTION (5)

Example 2

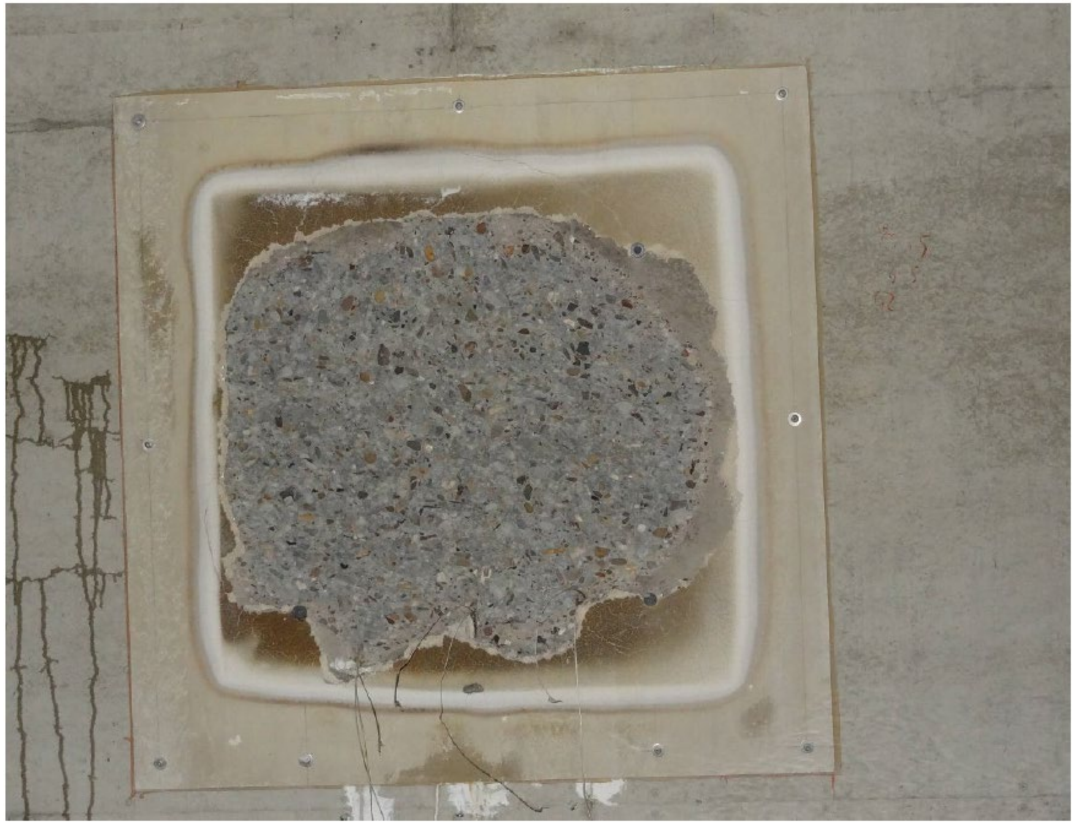


METHOD FOR CHOOSING THICKNESS OF PASSIVE FIRE PROTECTION (6)

Example 2



Before fire test



After fire test

METHOD FOR CHOOSING THICKNESS OF PASSIVE FIRE PROTECTION (7)

Results:

Example 1 – 60-minute requirement

→ Spalling at 59 minutes

→ Interface temperatures in the range of 187 to 228 °C

Example 2 – 120-minute requirement

→ Spalling at 100 minutes

→ Interface temperatures in the range of 312 to 361 °C

The fire tests of Example 1 and 2 were performed in the same tunnel but at different locations with different compressive stresses and concrete mixtures.

METHOD FOR CHOOSING THICKNESS OF PASSIVE FIRE PROTECTION (8)

Based on the results a fire protection system can be dimensioned.

Dimensioning takes place using data of laboratory fire tests, such as tests according to Chapter 5 *Thermal Insulation Tests* of Efectis-R0695.

The thickness is not only based on the insulating properties of a fire protection system but sometimes the behavior at joints must also be considered.

Some manufacturers have a software tool for calculating the required thickness.

METHOD FOR CHOOSING THICKNESS OF PASSIVE FIRE PROTECTION (9)

Example 1

→ A fire protection system with a thickness of 25 mm was chosen.

Example 2

→ A fire protection system with a thickness of 27.5 mm on 15 mm backing strips was chosen.

For both Examples 1 and 2 in-situ tests were performed to verify the design.

IN-SITU FIRE RESISTANCE TESTING (1)

Since the spalling behavior of concrete cannot be predicted beforehand fire testing is necessary.

For already existing tunnels this was difficult in the past.

Efectis has developed a mobile (portable) fire-resistance furnace – called MobiFire – to perform tests on concrete structures and fire protection systems on-site.

IN-SITU FIRE RESISTANCE TESTING (2)

The MobiFire fire-resistance furnace has the following characteristics:

→ Is able to reach the high temperatures of tunnel fire curves

→ Has a heated area with dimensions of 1 by 1 m

→ Propane fired – Propane taken from gas bottles with dip tube

→ Heat output of more than 550 kW

→ Can be used in both horizontal and vertical positions (i.e. for walls and ceilings)

→ Easily movable with a forklift

→ Has in-build protection to prevent misfiring

→ Can be used at other sites besides tunnels

Typically, all equipment – including the mobile furnace, control unit, gas bottles, forklift, diesel generator, small scissor lift, data acquisition system, etc. – is transported to the tunnel on a semi low loader.

IN-SITU FIRE RESISTANCE TESTING (3)

Typically, testing is done during a tunnel closure (during evening/night). Therefore, a limited amount of time is available to prepare and perform the tests. Typically, the work should be done in 7 hours or less.

Requirements:

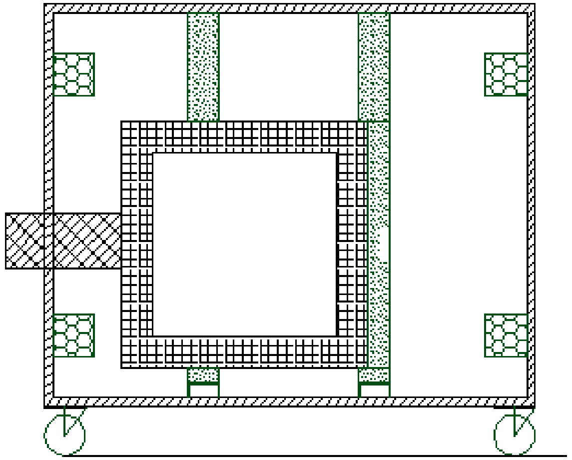
→ Well-ventilated area to prevent build-up of heat and smoke gasses. Tunnel ventilation should operate

→ No other work in the tunnel, especially downstream of the fire test

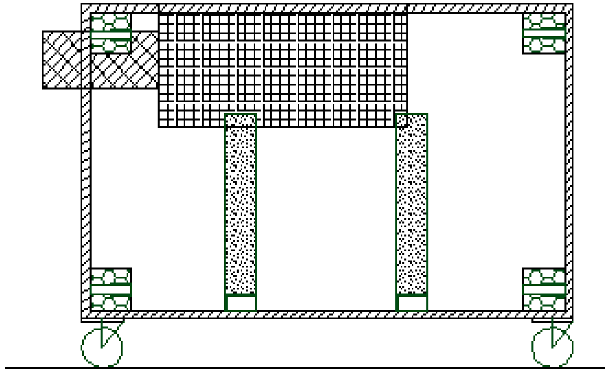
→ No traffic in the tunnel

IN-SITU FIRE RESISTANCE TESTING (4)

Vertical



Horizontal



IN-SITU FIRE RESISTANCE TESTING (5)

IN-SITU FIRE RESISTANCE TESTING (6)

IN-SITU FIRE RESISTANCE TESTING (7)

Efectis-R0695:2020 Fire testing procedure for concrete tunnel linings and other tunnel components

Chapter 7: Test protocol for mobile furnace tests

Chapter 7 gives guidance on different test setups, from unprotected concrete to existing fire protection systems and new-to-install fire protection systems

Chapter 7 gives guidance on how to determine the fire-resistance of a tunnel, given the fact that it is not possible to test every square centimeter (inch) of the tunnel interior

Efectis-R0695:2020 is freely downloadable from the Efectis website

IN-SITU FIRE RESISTANCE TESTING (8)

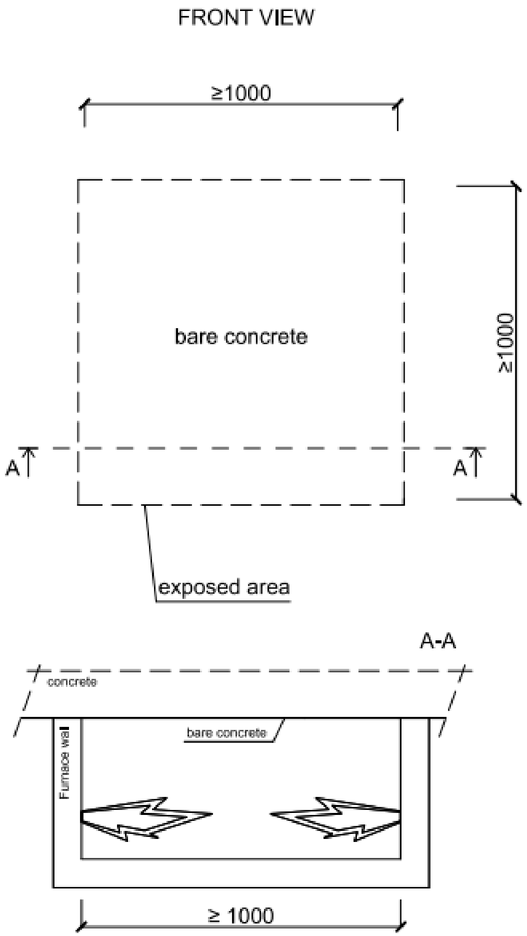


Figure 19 Fire test on bare concrete

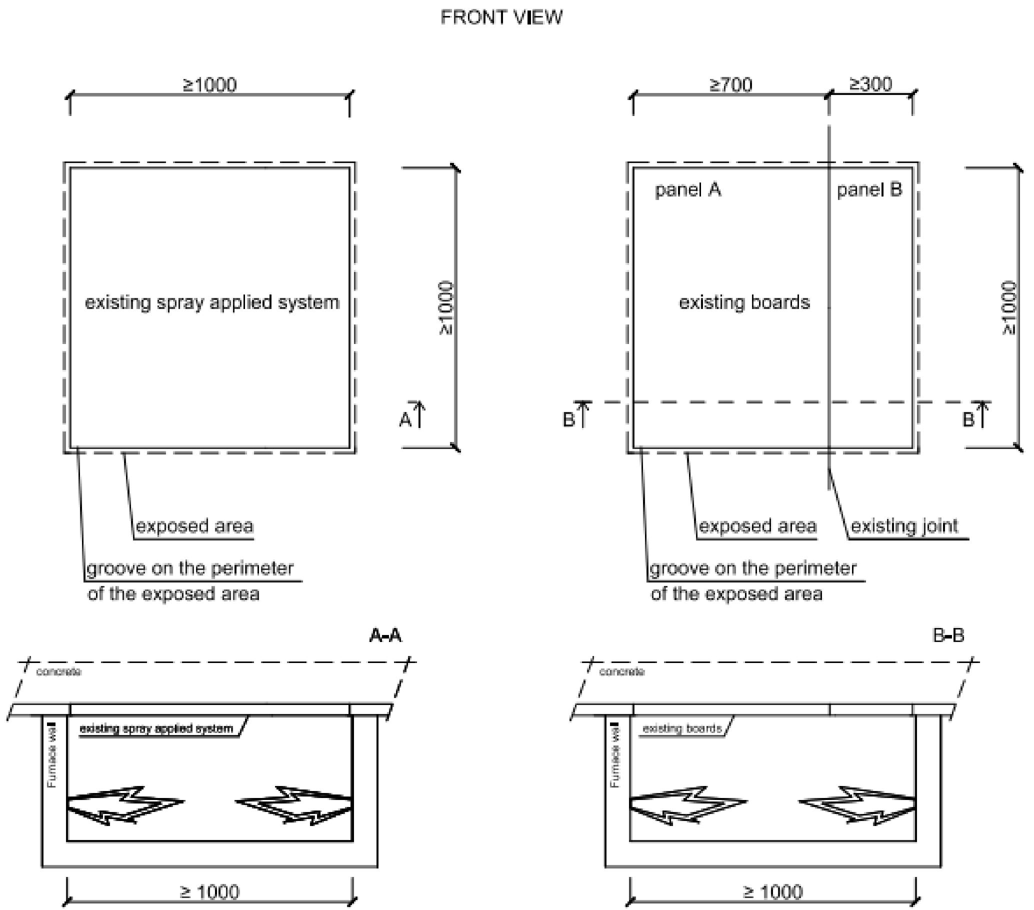


Figure 20 Fire test on existing pre-fixed and post-fixed fire protection systems

Source: Efectis-R0695:2020

IN-SITU FIRE RESISTANCE TESTING (9)

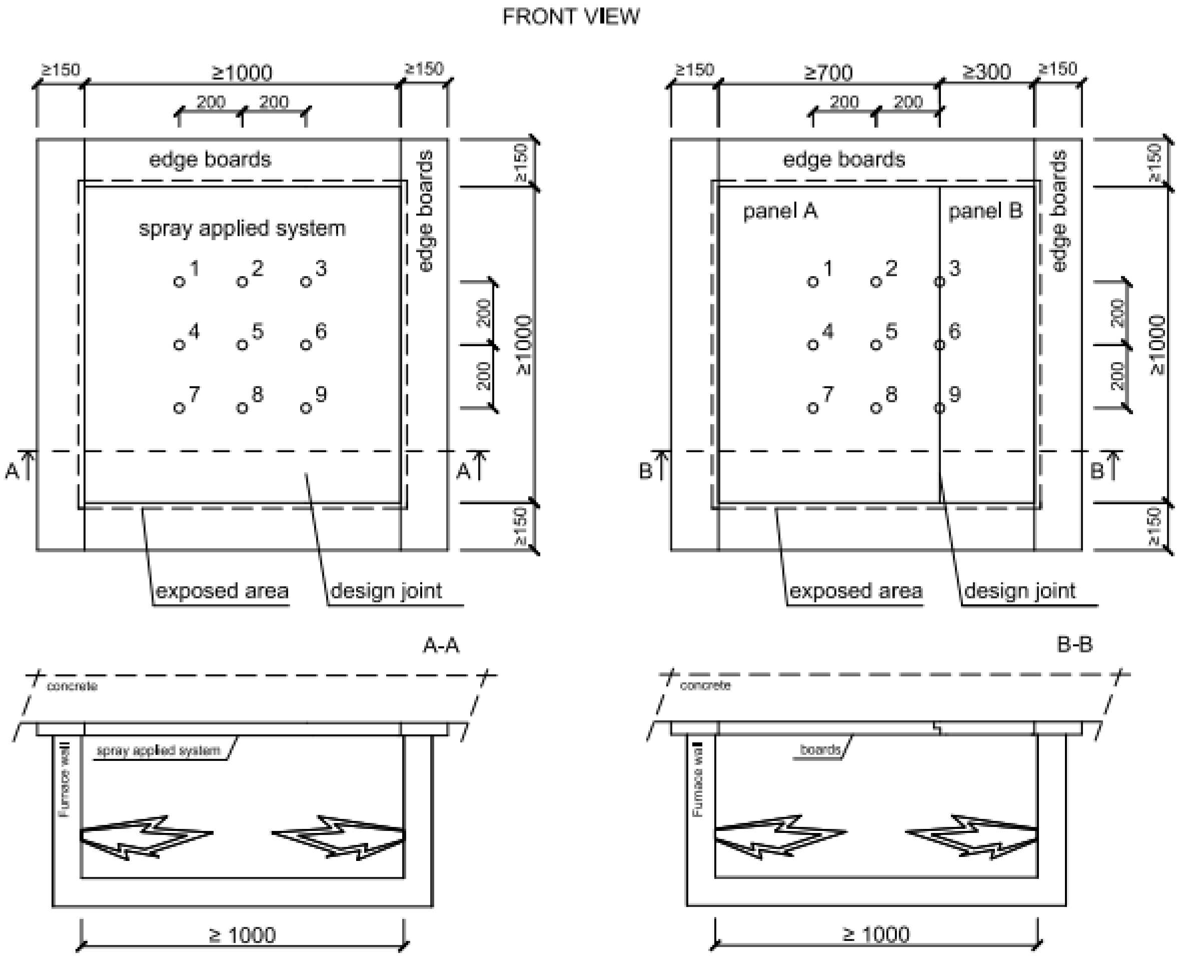


Figure 21 Fire test on new-to-apply fire protection systems

Source: Efectis-R0695:2020

Q&A

Questions?