Fire performance of tunnel linings

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Part of the BRE Trust

Scope of presentation

- Background
- Explosive spalling
- Test and assessment
- Research at BRE
- Commercial testing
- Crossrail – towards a standard specification?
- Next steps – HS2 and beyond

Background

- Explosive spalling – Channel tunnel (UK, 1996, 2006 and 2008, rail), Great Belt tunnel (DK, 1994, rail), Mont Blanc (It/Fr, 1999, road), Tauern tunnel (A,1999, road), Kaprun tunnel (A, 2000, rail), St Gotthard tunnel (CH, 2001, road), Daegu metro fire (SK, 2002, rail)
- Significant structural damage, consequential losses and loss of life

Explosive spalling

- Explosive spalling a function of a number of inter-related parameters
- Rapid rates of temperature rise
- Presence of restraint against thermal expansion
- Permeability (porosity, density, strength) of the concrete
- Tunnel fires often involve the use of high strength concrete. The nature of the construction involves significant restraint to thermal expansion and the nature of the fire load (petro-chemical fuel tankers) leads to rapid rise in temperature in the event of a fire

Test and assessment

- Given the nature of tunnel fires and the form of construction used in tunnels it is essential to ensure that the proposed design solution is capable of resisting a hydrocarbon fire while under load
- No standardised approach for the testing and approval of tunnel lining segments in relation to fire performance
- Some attempts made to produce standardised procedures but allow for flexibility in fire curve to be used. EFNARC (**E**uropean **F**ederation of **N**ational **A**ssociations **R**epresenting (producers and applicators of specialist building products) for **C**oncrete) recommendations do not require applied load.
- Requirements generally specific to individual project.

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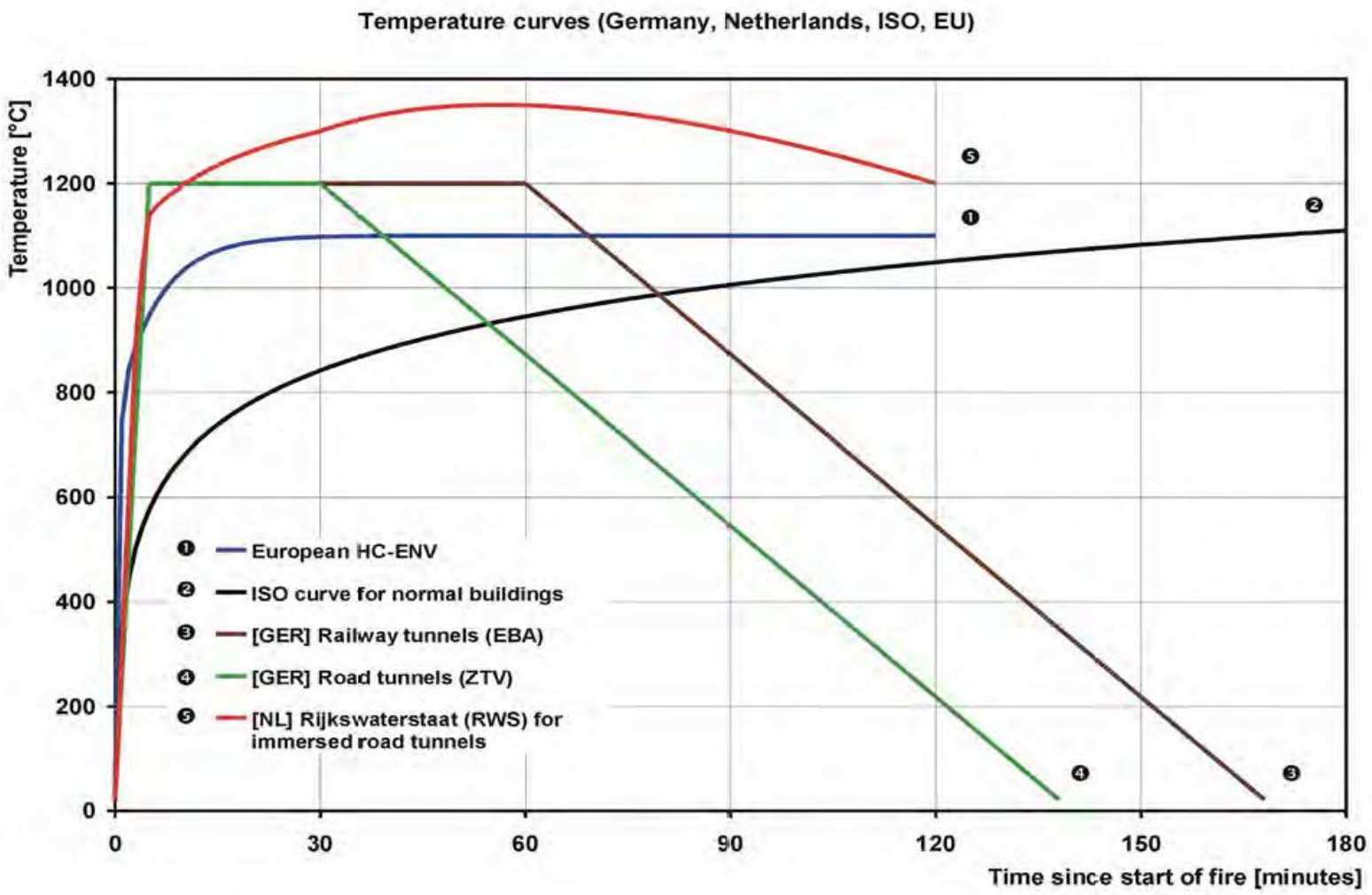
EFNARC

'achieving the highest standards'

Specification and Guidelines for Testing of Passive Fire Protection for Concrete Tunnels Linings

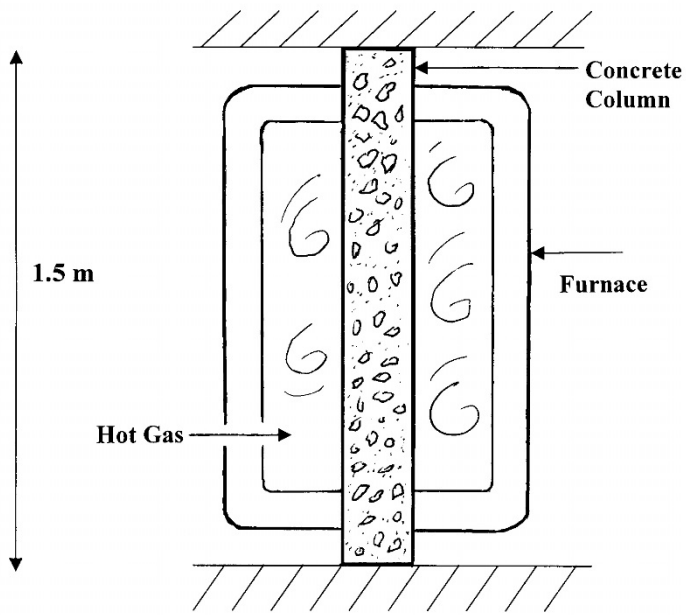
March 2006

EFNARC www.efnarc.org

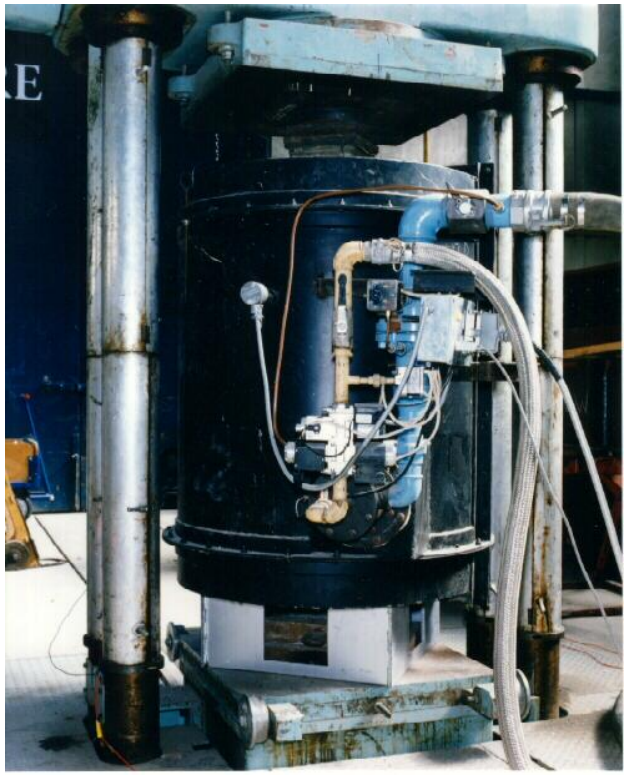

Temperature curves (Germany, Netherlands, ISO, EU)
Temperature [°C]
1400
1200
1000
800
600
400
200
0
0
30
60
90
120
150
180
Time since start of fire [minutes]
❶ European HC-ENV
❷ ISO curve for normal buildings
❸ [GER] Railway tunnels (EBA)
❹ [GER] Road tunnels (ZTV)
❺ [NL] Rijkswaterstaat (RWS) for immersed road tunnels

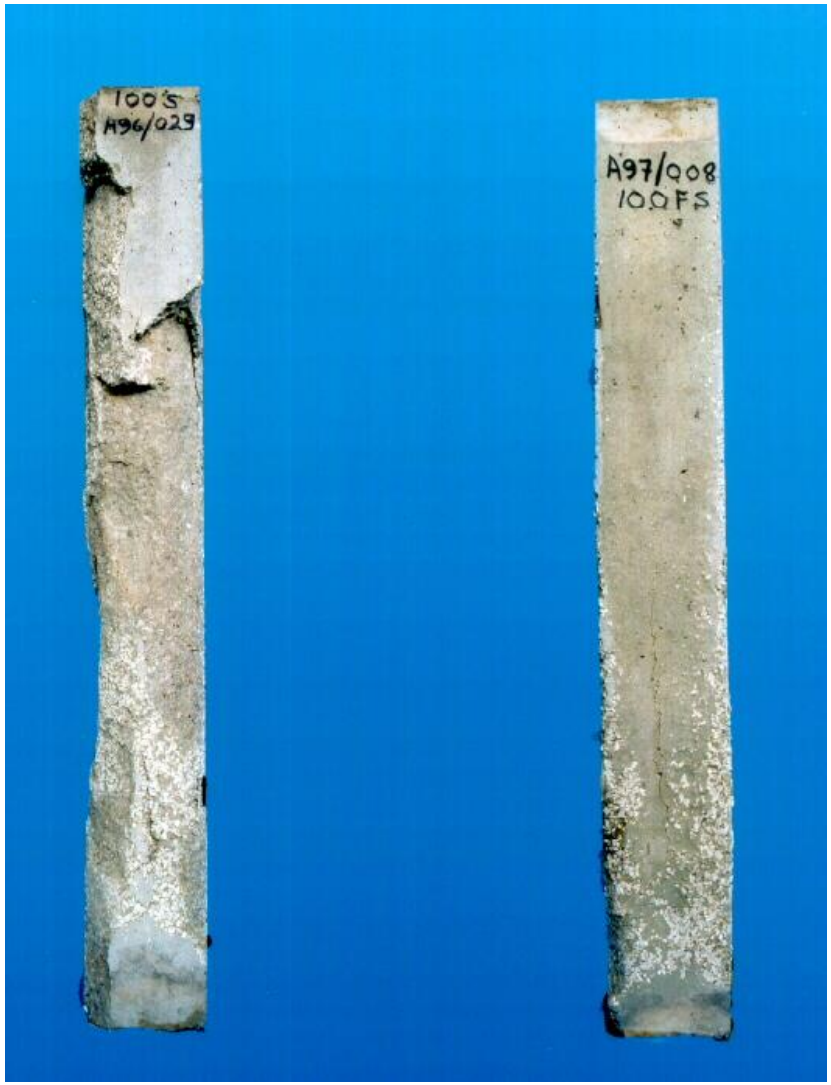
Research at BRE

- Early work on the use of high strength (>70MPa) concrete columns in buildings with a focus on the tendency of such elements to spall in an explosive manner due to a combination of pore pressure and thermal stress.
- Use of polypropylene fibres to prevent spalling.
- A number of columns were subject to a combination of axial load applied using a 500 tonne compression machine and a fire exposure provided by a portable gas fired furnace.



Compression Machine




100'S
A96/029
A97/008
100FS

bre

BRE
Garston, Watford, WD2 7JR

2000

Effect of polypropylene fibres on performance in fire of high grade concrete

N Clayton and T Lennon

BRE Centre for Concrete Construction

DETR

BRE

constructing the future

Research informed decisions on column design for ECBP Cardington

Commercial testing

- BRE have provided specialist fire test services for a number of high profile tunnel projects including:
  - Channel Tunnel Rail Link
  - Heathrow T5
  - Hindhead Road Tunnel

  - The expertise derived from these projects provided input to the specification for fire testing of Sprayed Concrete Linings for the Crossrail project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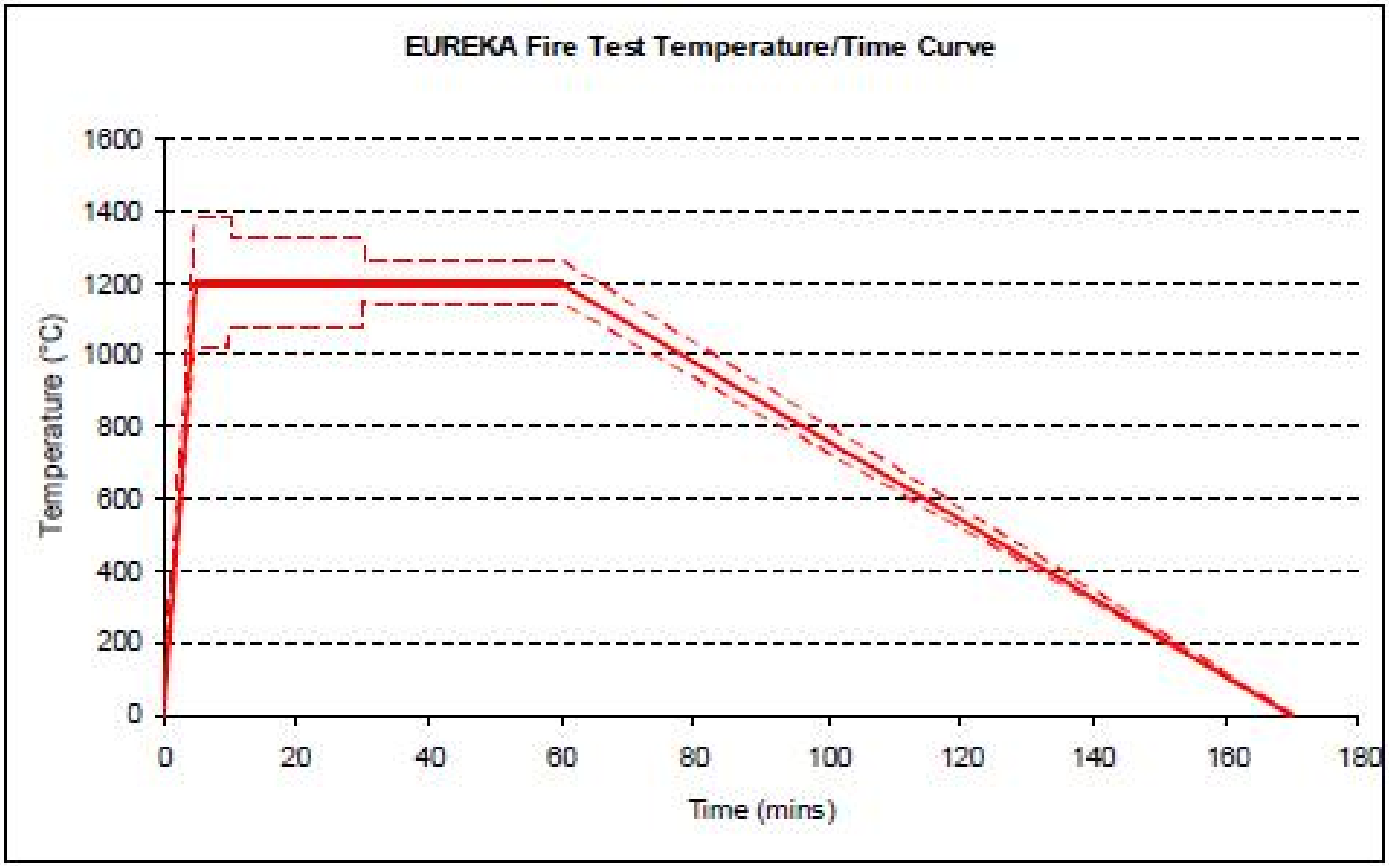
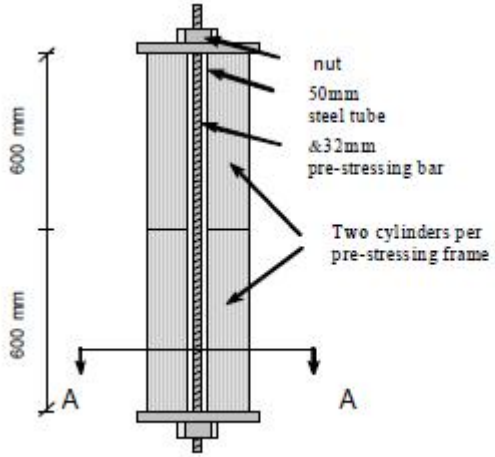
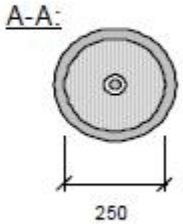
Crossrail

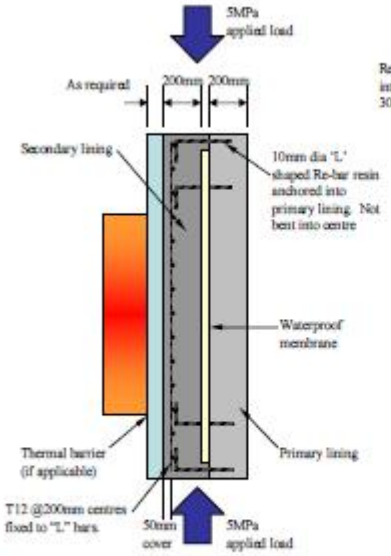
- Two different specifications for SCL tunnels and precast tunnel linings
- Both SCL and precast segmental units require the use of the Eureka time curve (curve 3 in slide above) - 1200° C in 5 minutes
- SCL require an applied load (axial compression) of 5MPa
- For SCL both small and large scale test samples (250mm diameter cylinders and 1700mm x 800mm x approximately 450mm slabs)
- Performance criteria is based on depth of spalling, temperature rise within the slab (impact on waterproof material) and residual strength of heated concrete


EUREKA Fire Test Temperature/Time Curve
Temperature (°C)
1600
1400
1200
1000
800
600
400
200
0
0
20
40
60
80
100
120
140
160
180
Time (mins)

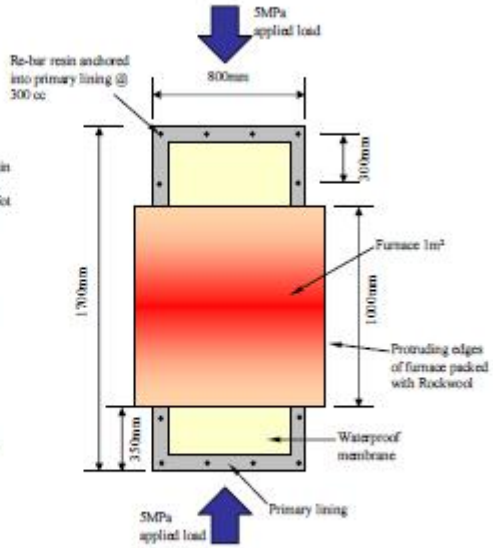
Crossrail specification – small and large scale test specimens





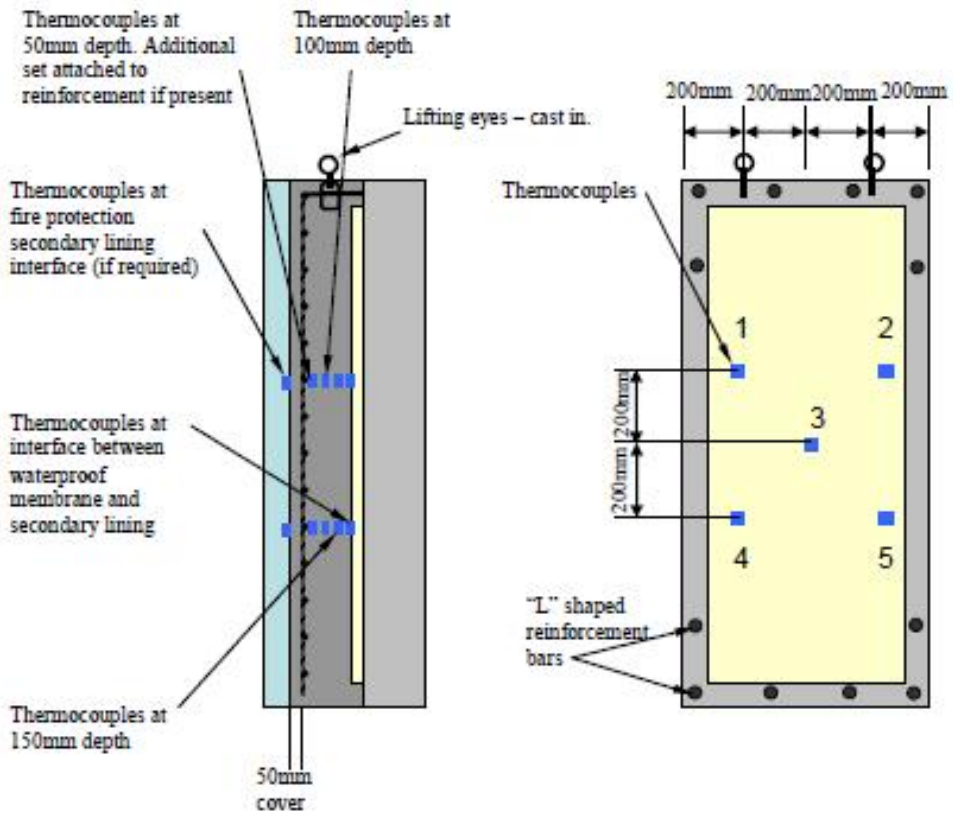


Section through sample



Plan on sample

Crossrail thermocouple specification



Thermocouples installed on site

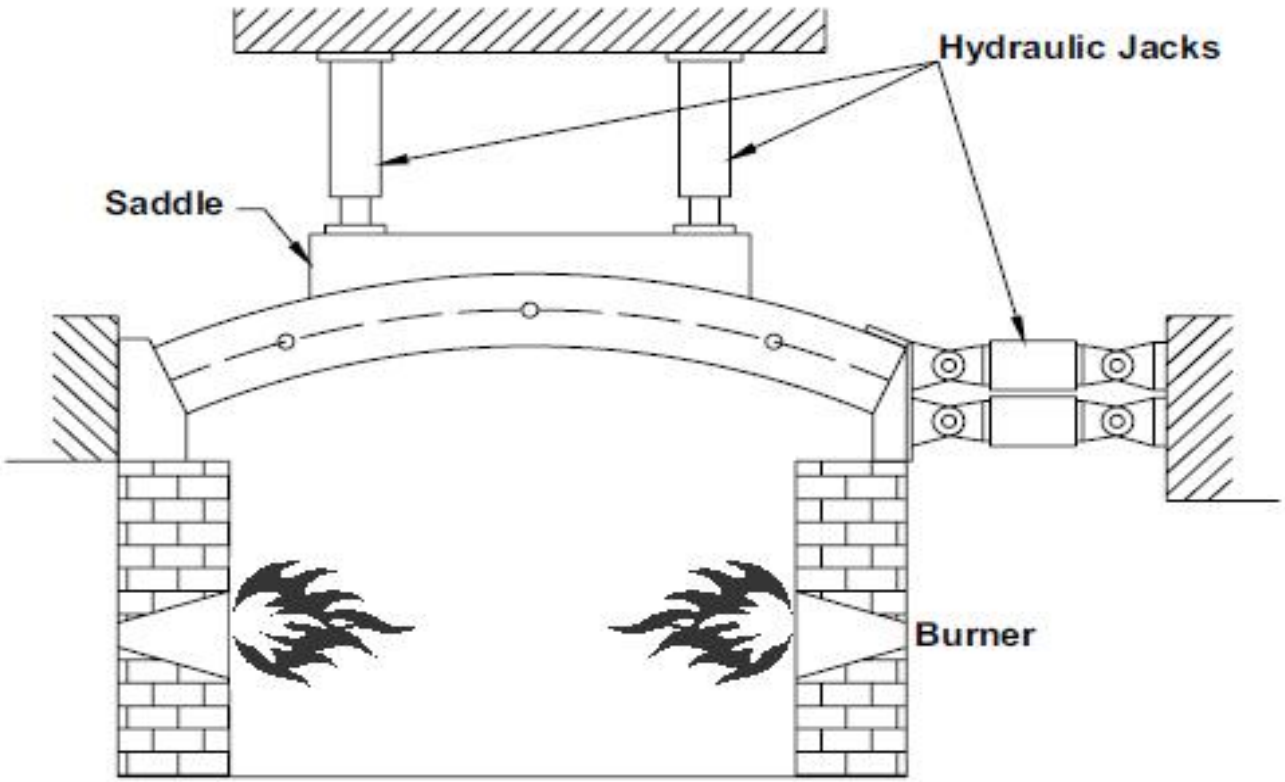
Cured under specified conditions for temperature and humidity

Test specimen under load

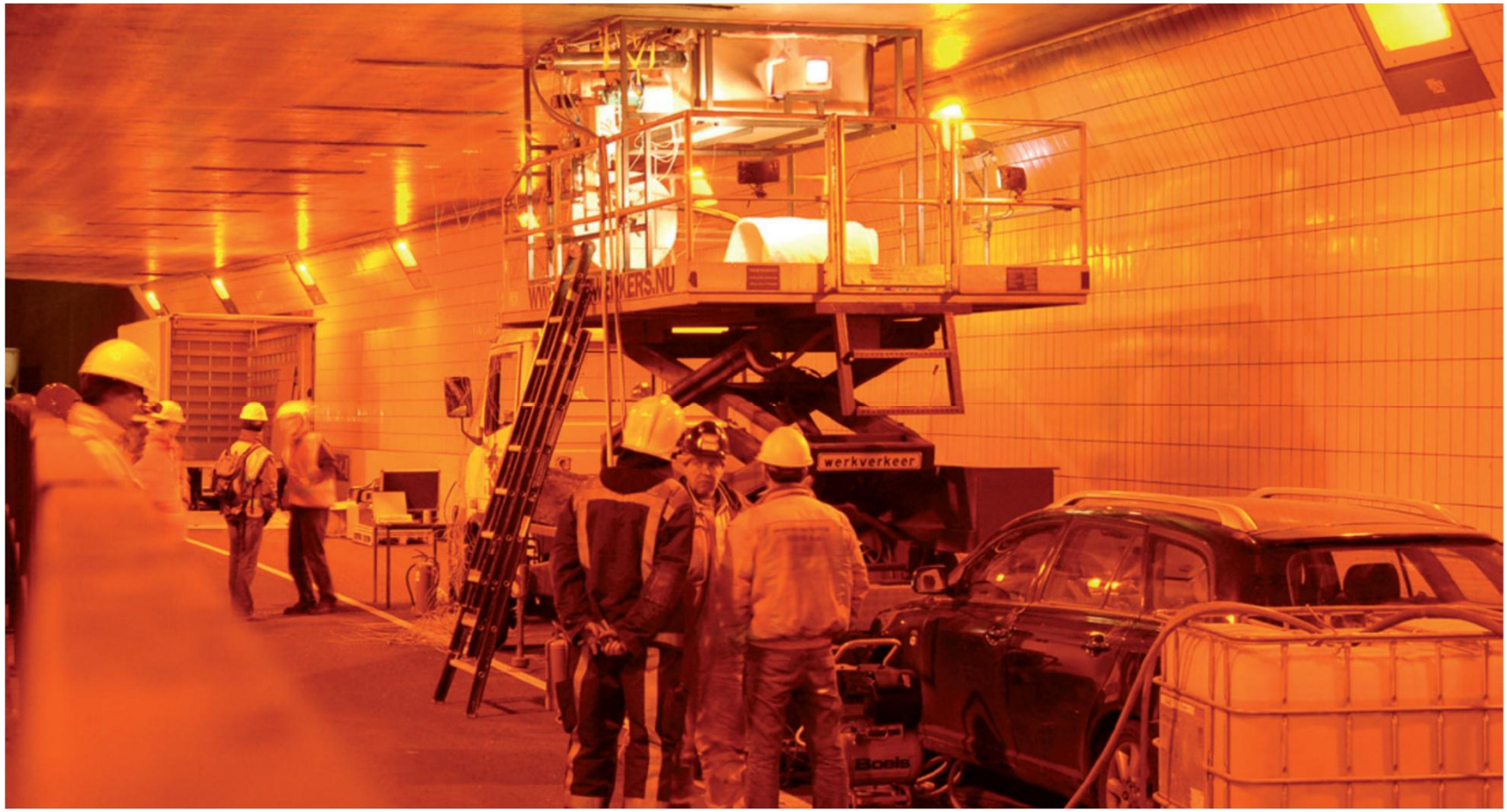
Full depth cores from heated area

Crossrail specification for precast linings

- Same fire curve specified
- Different specimen size and shape (“small” scale specimens (unloaded) 2000mm x 2000mm x 300mm panels); Second stage testing on prototype segments (see Figure)
- Different loading arrangement
- Lack of expertise in relation to fire testing of tunnel lining segments
- Specification dependent on experience of consultants employed to develop it


Hydraulic Jacks
Saddle
Burner

Portable Furnace testing



Next steps – HS2 and beyond

- Specification prepared for fire testing of tunnel linings for HS2
- Specification applicable to all permanent concrete in tunnels and other underground structures that may be exposed to a fire during operation.
- No distinction between SCL and precast units.

Concluding remarks

- A standardised procedure needs to be developed which allows for flexibility depending on specific circumstances of project
- The Crossrail SCL specification and current HS2 specification could provide a useful starting point to specifying a fire test and assessment methodology which is robust and does not impose an unreasonable financial burden on contractors