



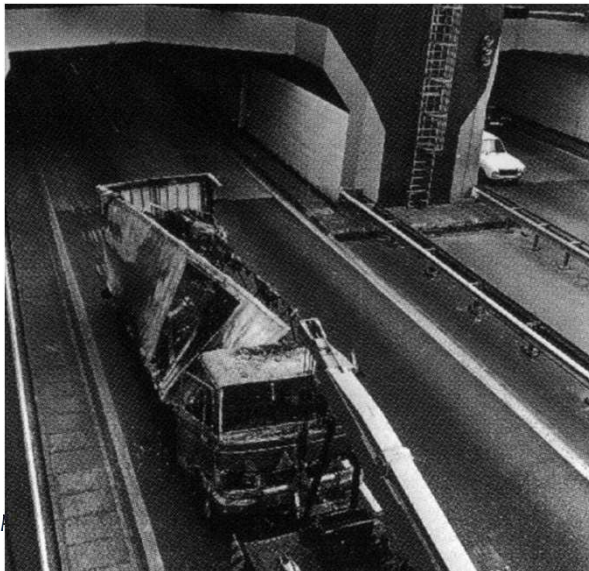
# FIRE TESTING OF CONCRETE TUNNEL SEGMENTS

KAMAKSHI PARWANI

# FIRE AND TUNNELS

---

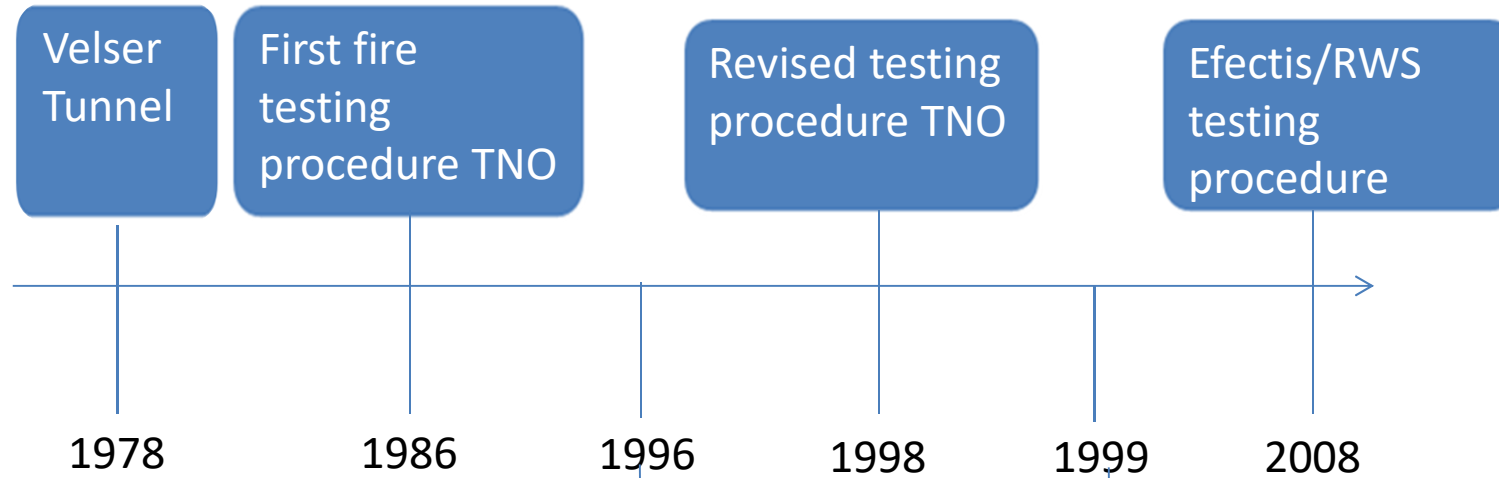
- ❑ 1975-1978: attention of Dutch Ministry of Transport (RWS) to tunnel fires, especially after fire in the Velser Tunnel (Netherlands)
- ❑ 1979-1980: TNO small scale fire tests to establish “RWS fire curve” with a maximum of 1350°C
- ❑ 1986: TNO and RWS publish fire test procedure for concrete structures in tunnels
- ❑ 1998: TNO and RWS publish new version of fire test procedure
- ❑ 2003: European UPTUN project (led by TNO) performs full scale fire tests in Runehamar tunnel (Norway) and confirms the RWS fire curve
- ❑ 2006: TNO Centre for Fire Research becomes Efectis
- ❑ 2008: Efectis and RWS publish latest version of fire test procedure (2008-Efectis-R0695)



Velser  
Tunnel

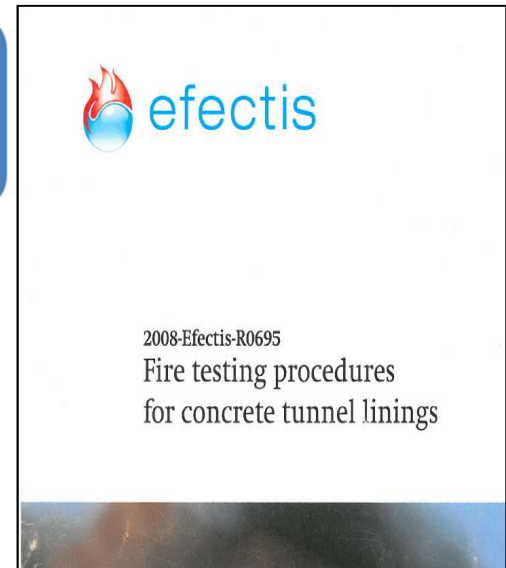


# FIRE AND TUNNELS



Channel tunnel fire

Mont Blanc tunnel fire



# CONCRETE THERMAL BEHAVIOUR (KNOWN)

☐ EUROCODE 1992-1-2

- Method for determination of the minimum thickness for concrete load bearing and non-load bearing elements
- Simple tables
- ISO/cellulosic fire curve

☐ Concrete at a temperature more than 500 °C is neglected in the calculation of load-bearing capacity, while concrete at a temperature below 500 °C is assumed to retain its full strength.

☐ Spalling- When using tabulated data no further check is required for normal weight concrete

Standard fire resistance	Minimum dimensions (mm)			
	slab thickness $h_s$ (mm)	axis-distance $a$		
		one way	two way:	
			$l_x/l_y \leq 1,5$	$1,5 < l_x/l_y \leq 2$
1	2	3	4	5
REI 30	60	10*	10*	10*
REI 60	80	20	10*	15*
REI 90	100	30	15*	20
REI 120	120	40	20	25
REI 180	150	55	30	40
REI 240	175	65	40	50

$l_x$  and  $l_y$  are the spans of a two-way slab (two directions at right angles) where  $l_y$  is the longer span.

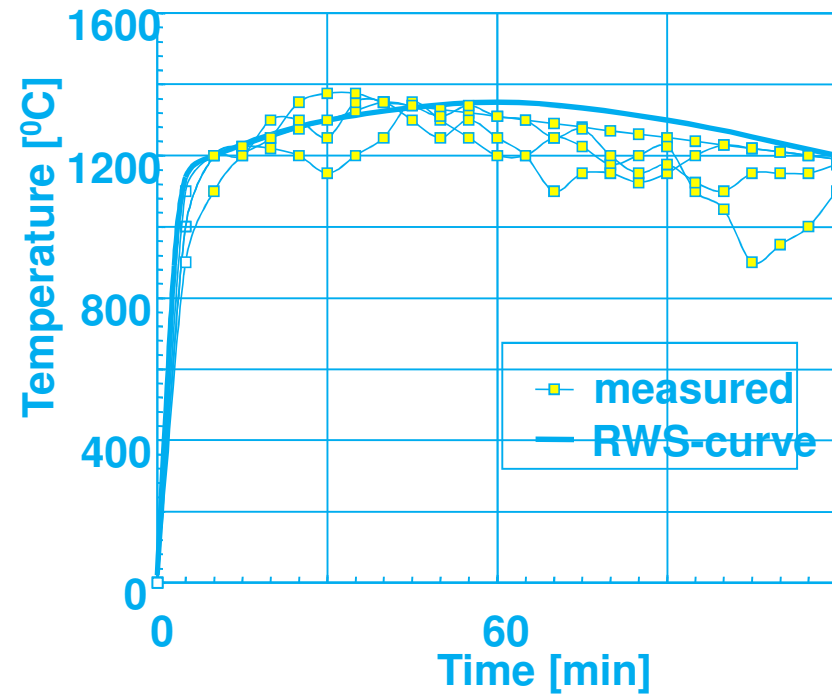
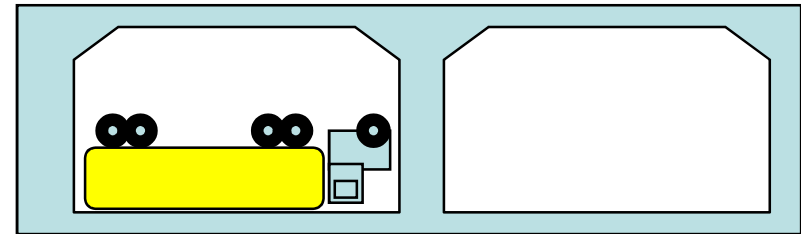
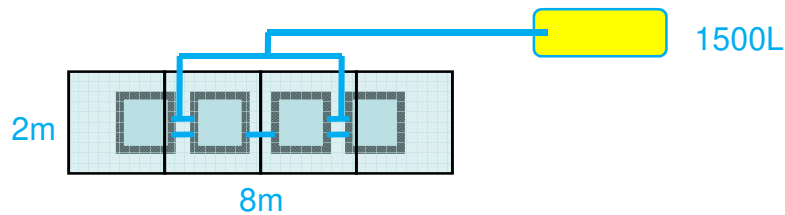
For prestressed slabs the increase of axis distance according to 5.2(5) should be noted.

The axis distance  $a$  in Column 4 and 5 for two way slabs relate to slabs supported at all four edges. Otherwise, they should be treated as one-way spanning slab.

\* Normally the cover required by EN 1992-1-1 will control.

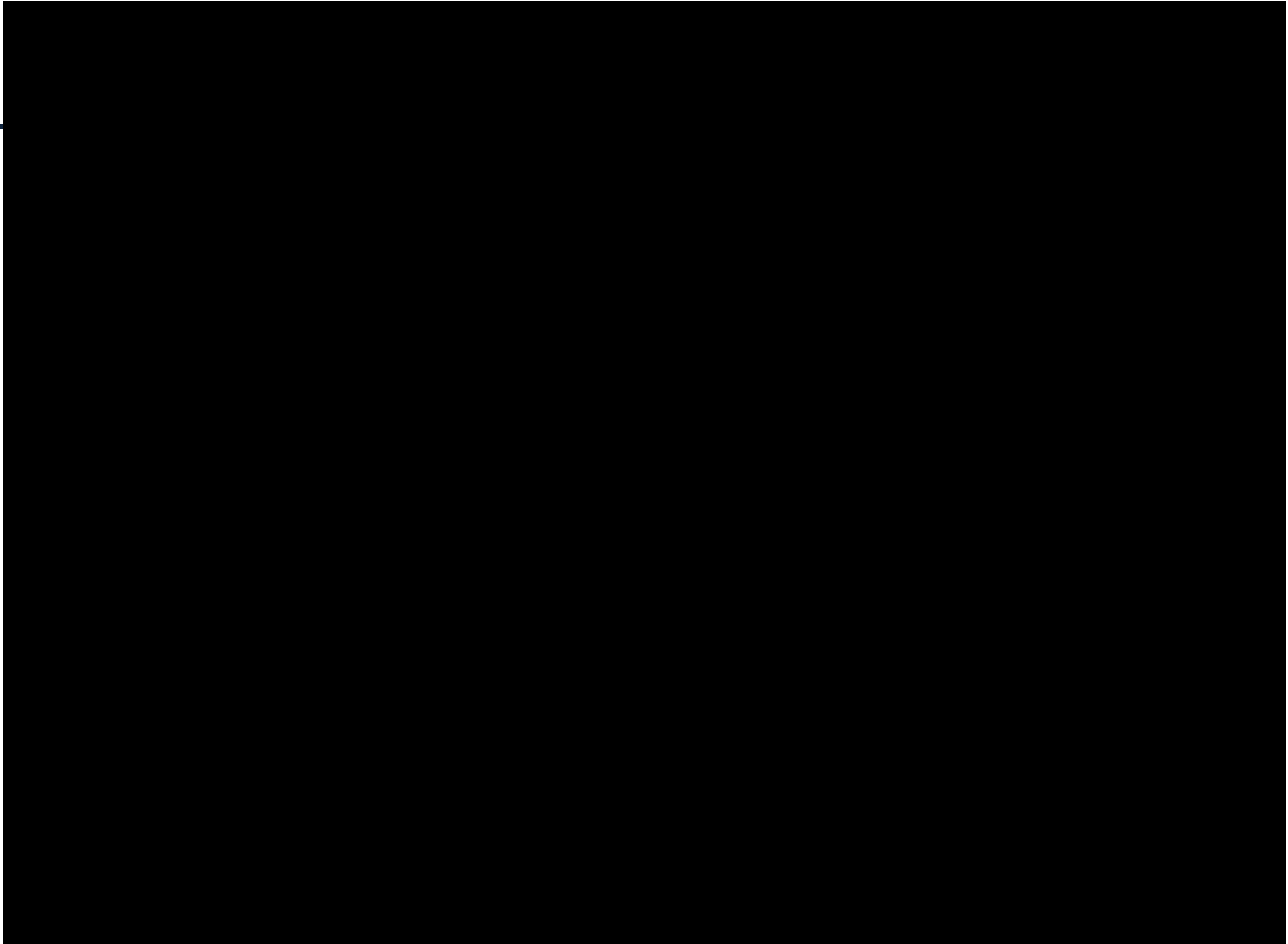
# FIRE TEMPERATURE

- ❑ Structural integrity: deterministic approach
- ❑ Credible worst case scenario:
  - crash with 50 m<sup>3</sup> petrol tanker
  - pool size some 150 m<sup>2</sup>
  - 300 MW
  - 90-120 min “leakage”
- ❑ Small scale test => RWS-fire



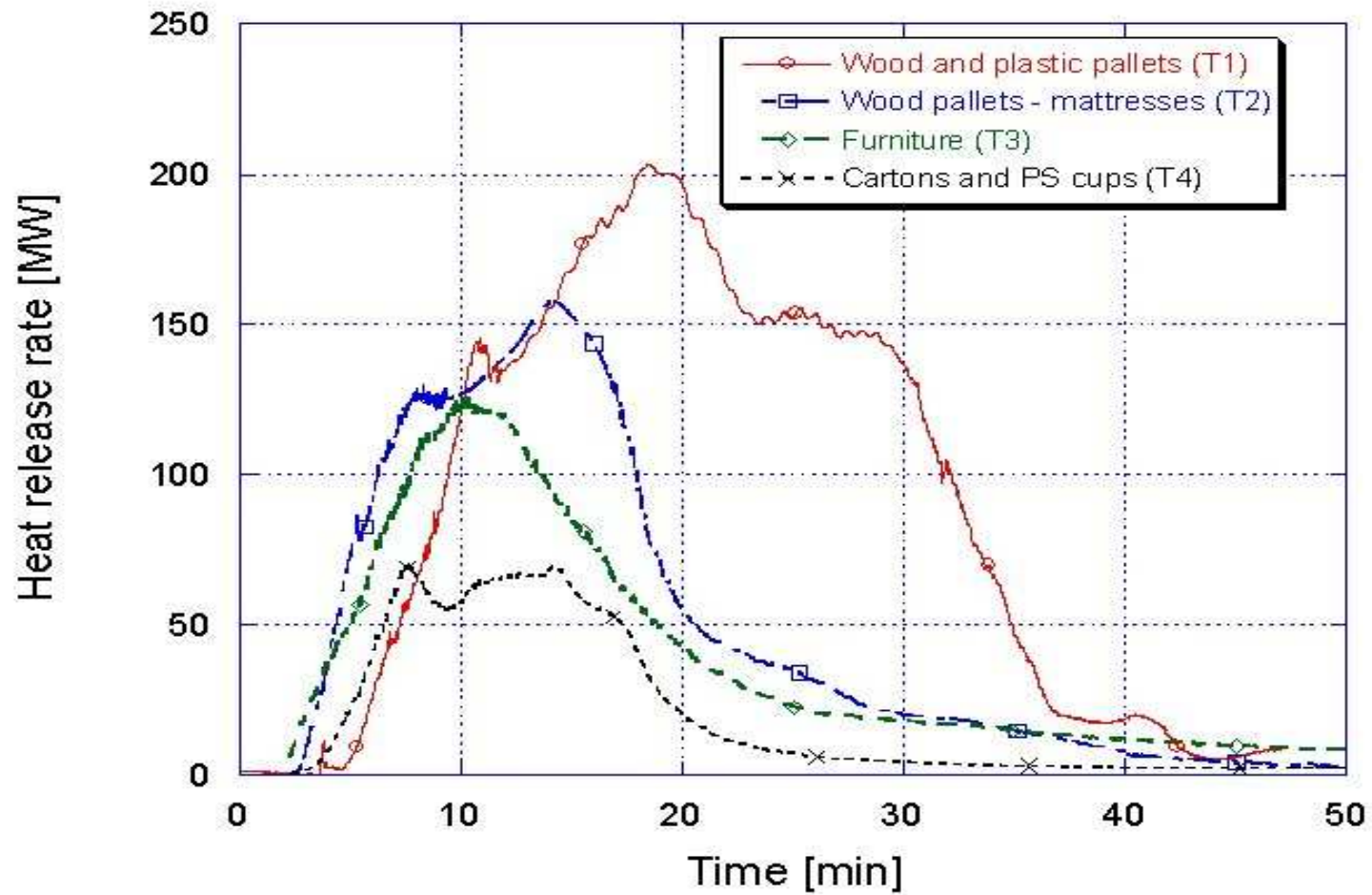




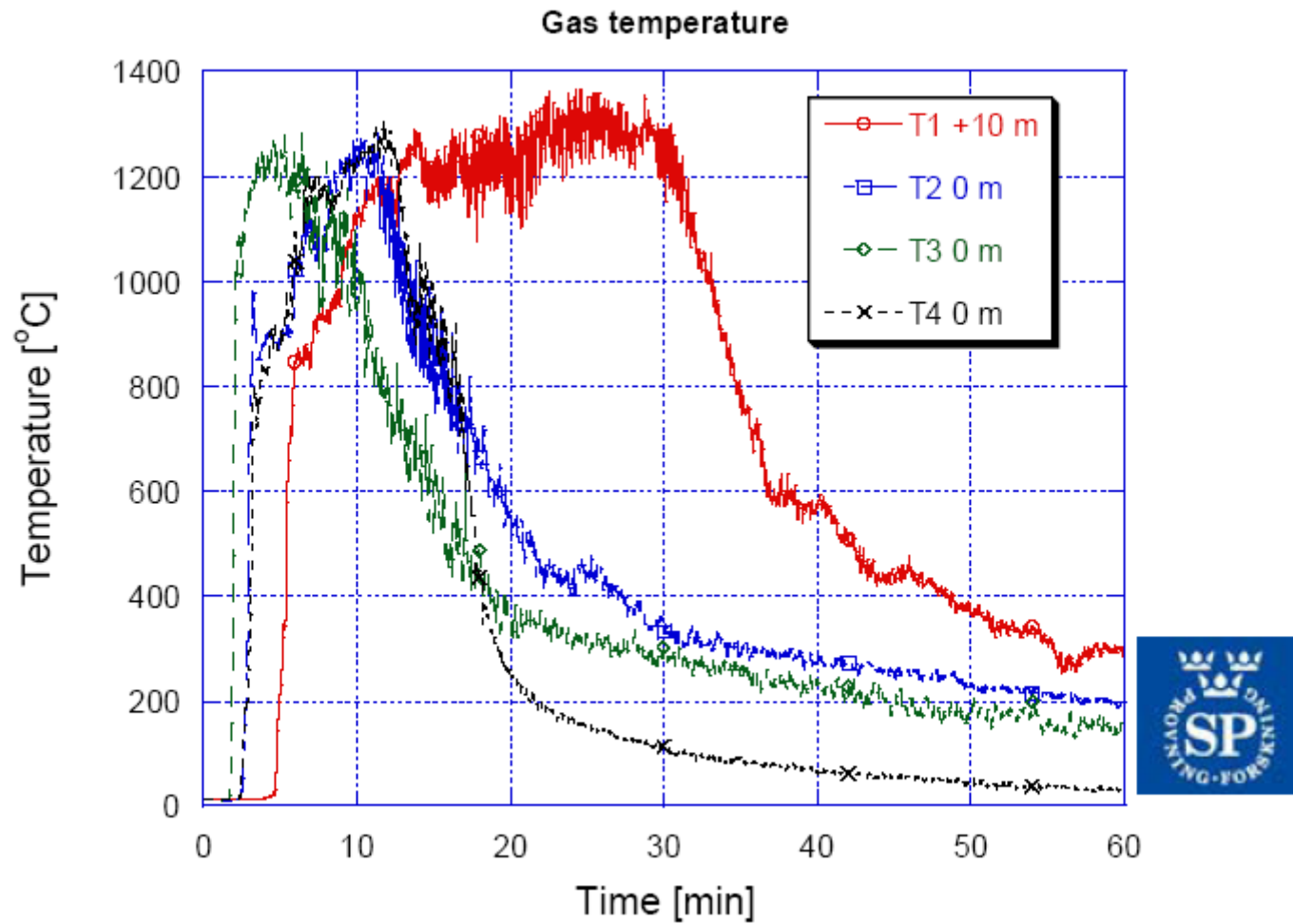




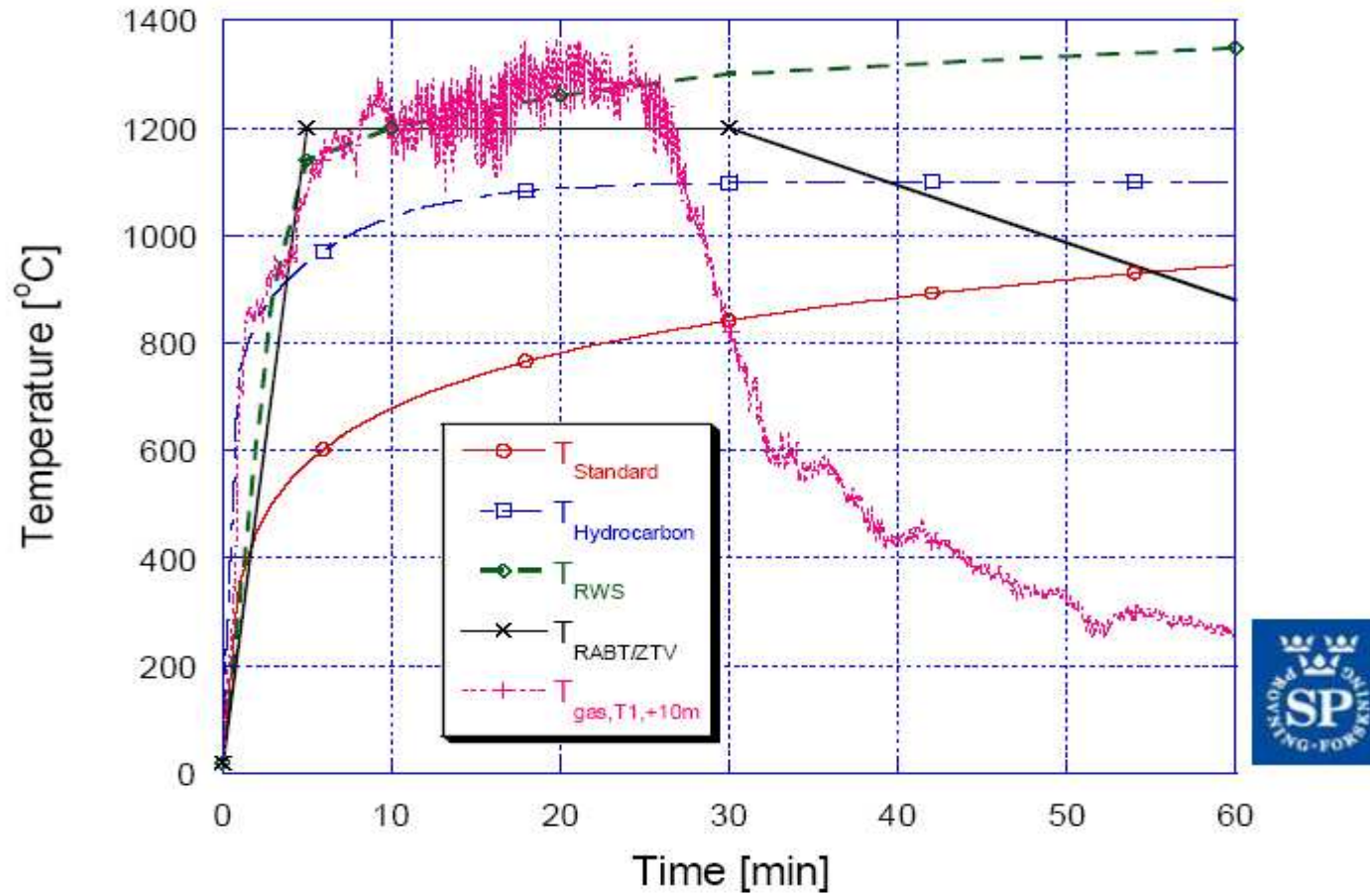
# HEAT RELEASE RATE



# GAS TEMPERATURES NEAR FIRE

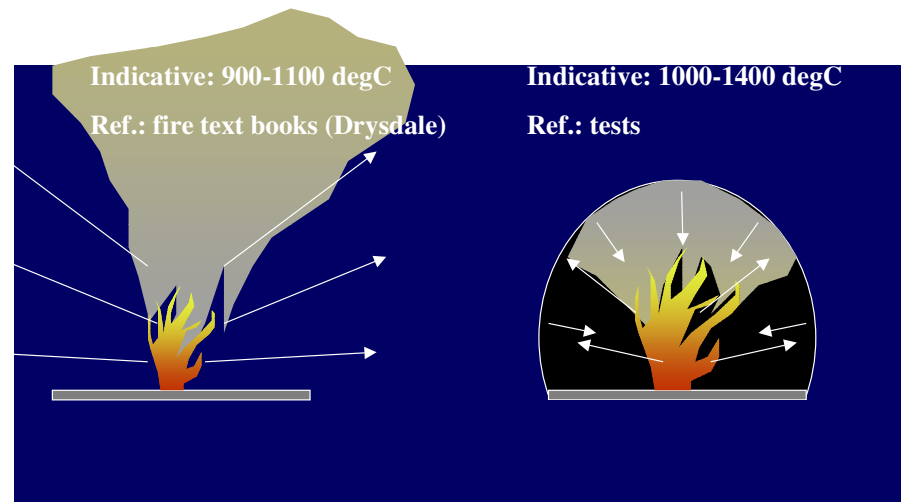
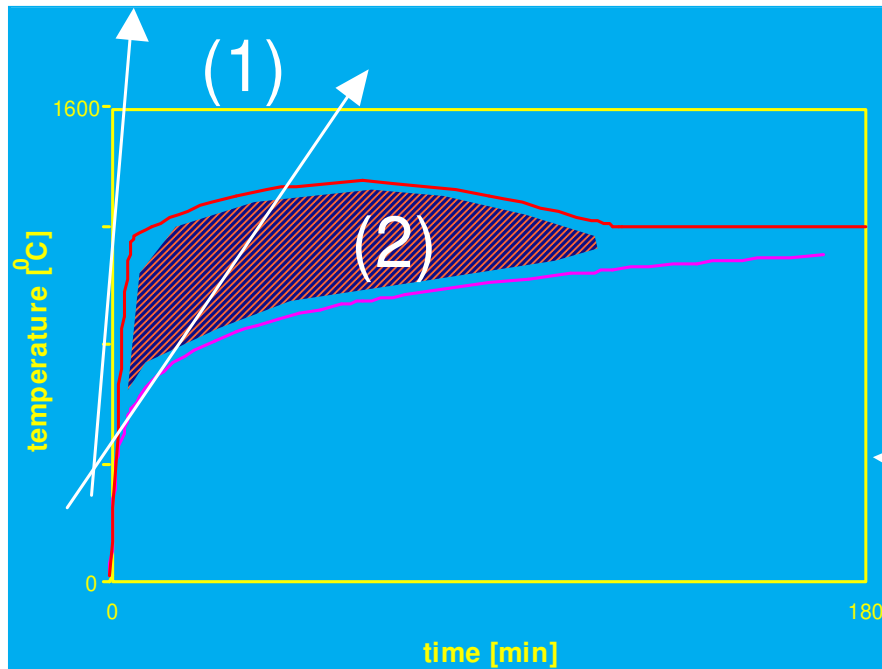


# GAS TEMPERATURE COMPARISON



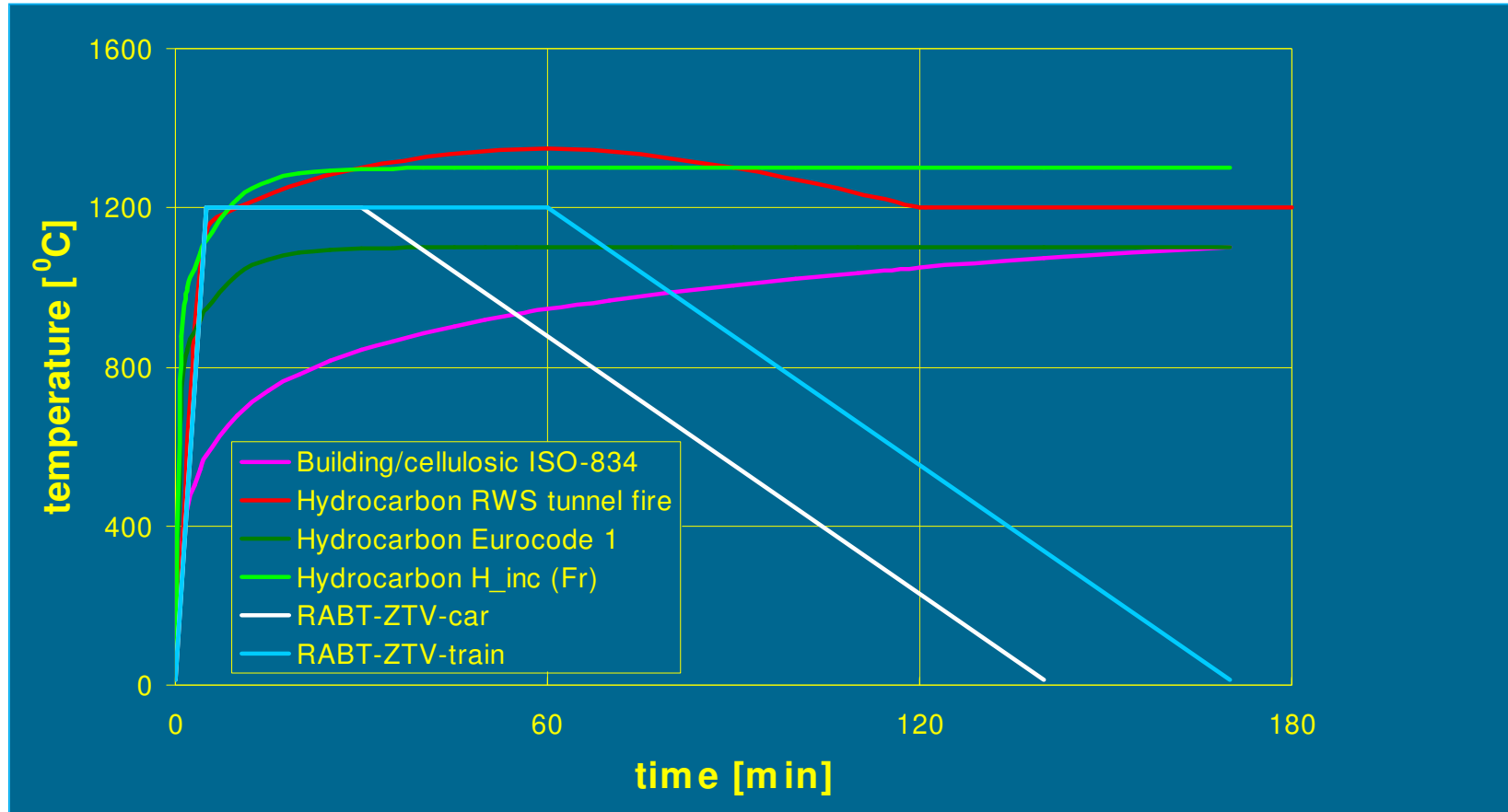
# RWS VS ISO CURVE

- ❑ Note: above 1200 °C “ordinary” insulation melts / disintegrates
- ❑ Main differences (building) cellulosic - hydrocarbon (tunnel) fires
  - (1) Heating rate in first (critical) 30 min
  - (2) maximum temperatures during first 2 hours



# FIRE CURVES

- Comparison of the nominal fire curves



# CONCRETE THERMAL BEHAVIOUR (UNKNOWN)

---

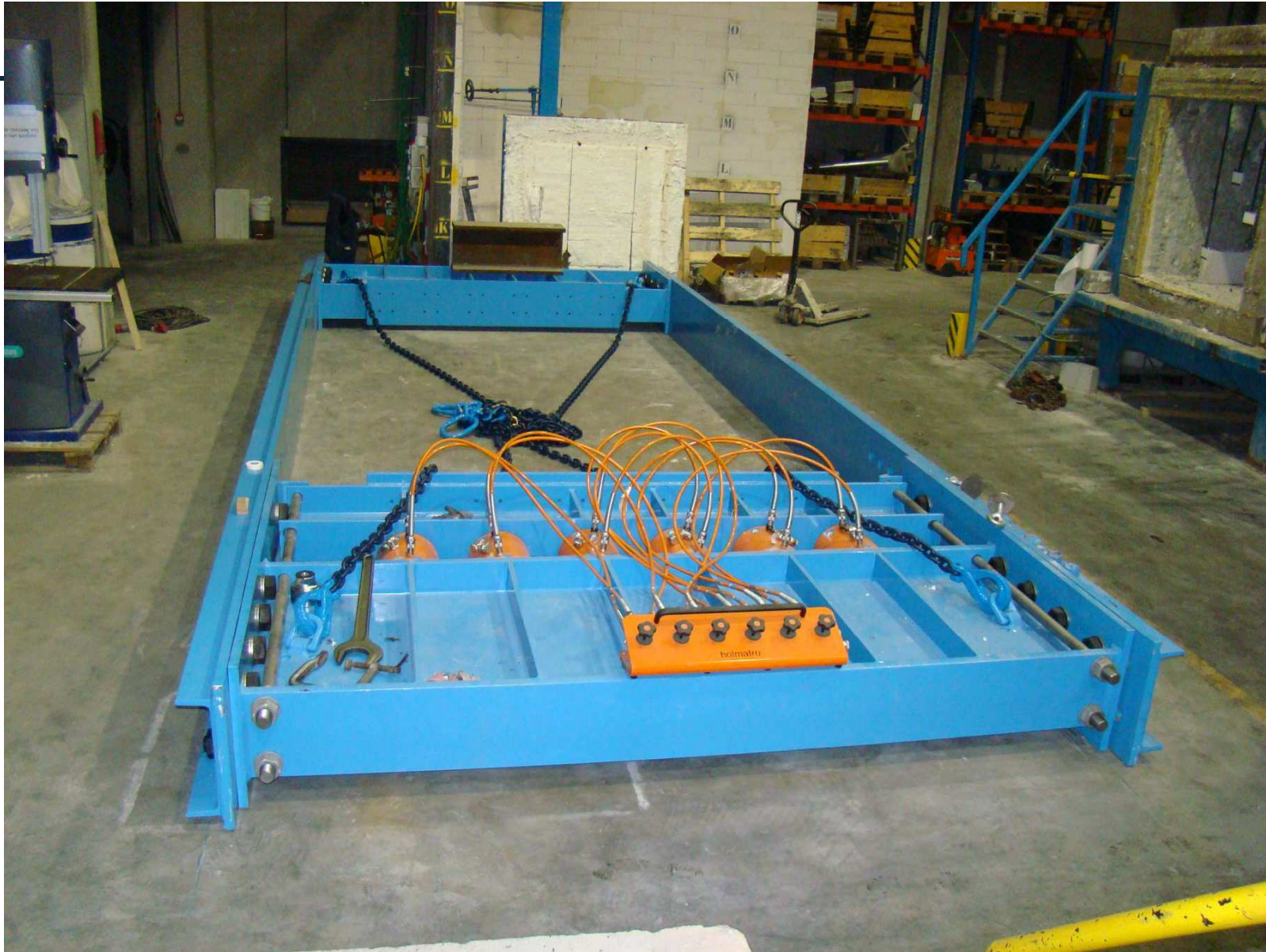
- ❑ EUROCODE 1992-1-2 **ISO**
  - RWS, HCM, RABT, MOAC fire curve
  
- ❑ Temperature more than 500 °C - is it realistic ? Concrete with protection generally starts spalling before 500 °C
  
- ❑ Spalling- non-linear and unpredictable process



# TEST FURNACE IN BLEISWIJK, NL

---









# SPALLING TEST

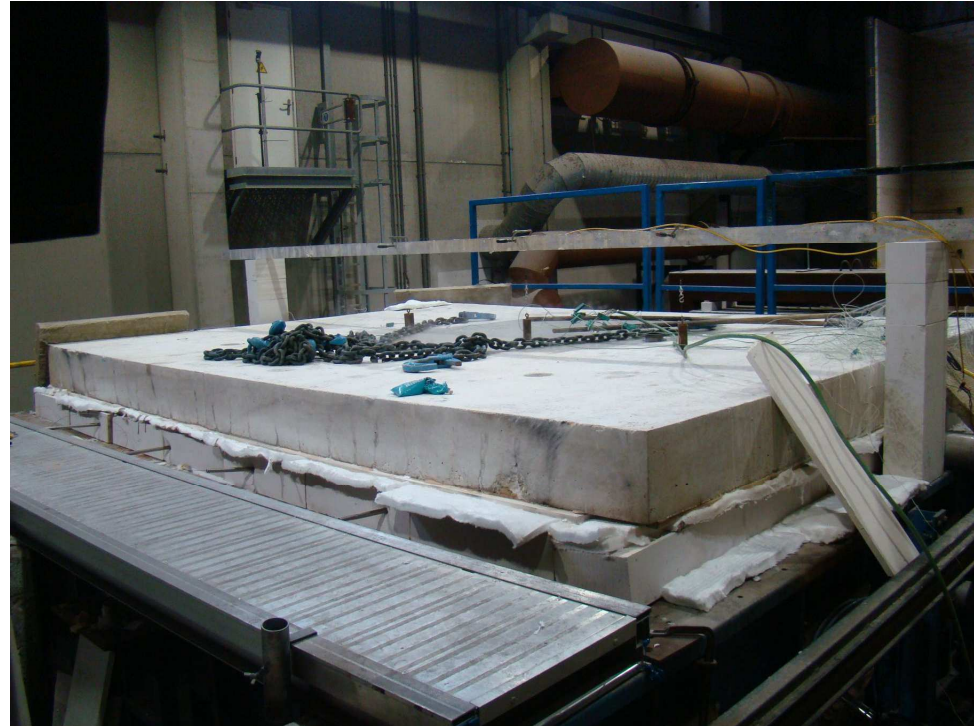
- ❑ Two identical tests
- ❑ Full scale, real geometry
- ❑ Real concrete mix
- ❑ Realistic loading
- ❑ Cast in realistic direction
- ❑ Concrete age > 3 months at time of testing



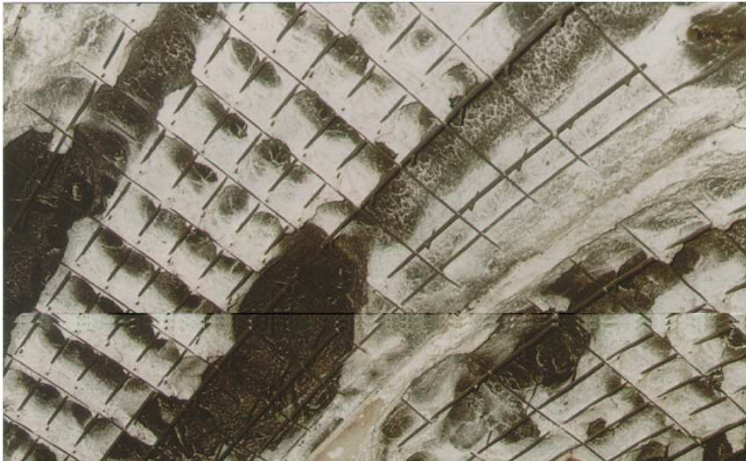
# THERMAL INSULATION TEST

---

- ❑ Tests with minimum and maximum protection thickness
- ❑ Concrete mix less susceptible to spalling
- ❑ Unloaded
- ❑ Concrete age > 3 months



# SPALLING OF CONCRETE IN REAL TUNNELS



# FIRE IN RECENT TIMES

---



a truck caught fire there. The vehicle is burned out, the fire brigade put out under dangerous



7|27 Lkw-Brand: Aufnahmen der Bergungsarbeiten.  
Bild: Thomas Lenger

Tunnel Rannersdorf ,  
Austria  
29 April 2019



## FIRE IN RECENT TIMES

---



▲ De brand is inmiddels geblust. © Rijkswaterstaat

### **Uitgebrande vrachtauto verwijderd: Beneluxtunnel weer open**

Beneluxtunnel,  
Netherlands  
10-05-2019



# CONCRETE MIX

---

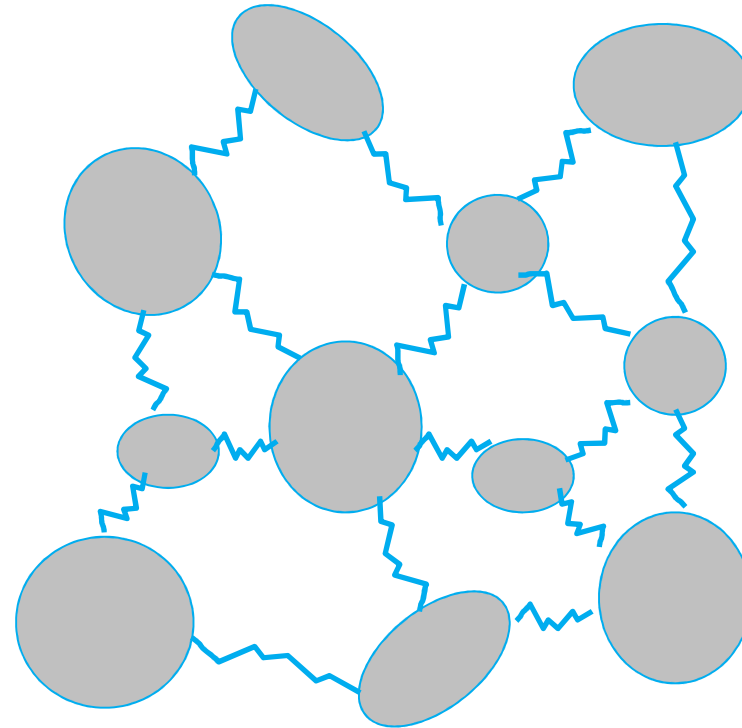
- ❑ Thermally stable aggregate
  - Granite, basalt
  - Limestone (however spalls during cooling down)
  - Avoid large grain diameters
  
- ❑ Permeability
  - Cement type
  - Avoid micro-fillers
  
- ❑ Combination with steel / PP - fibres



# STRENGTH LOSS DUE TO INTERNAL MICRO-CRACKING

---

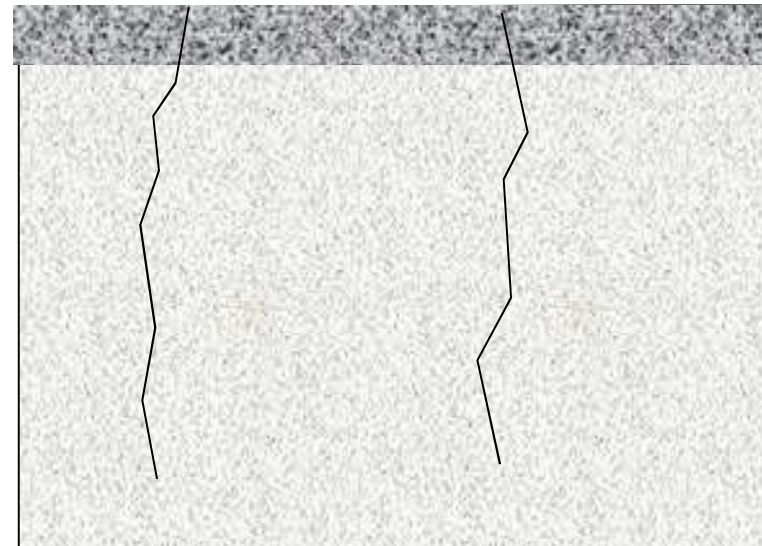
- ❑ Aggregate expands
- ❑ Cement paste shrinks
- ❑ Compression of aggregate grains, tension in cement paste
- ❑ Cracking of cement paste



# POLYPROPYLENE FIBRES

---

- ❑ Can reduce spalling
- ❑ Strongly dependent on fibre type, geometry and mixing
- ❑ Usually still some spalling  
(melting at 170 °C)



# EXTERNAL PROTECTIVE LAYER

---

- ❑ Spray mortar / board material / coating
- ❑ Concrete temperatures are reduced



# BOARD MATERIAL

---

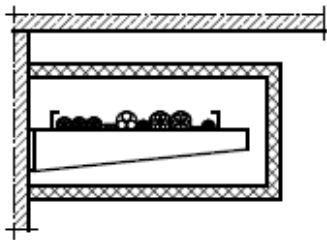
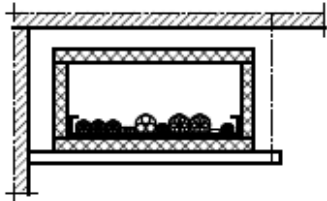
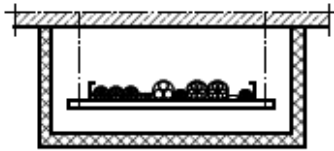
- ❑ In rectangular tunnels
  - Can be used as lost formwork
  
- ❑ In circular tunnels
  - Limited possibility to bend plates / also used as faceted lining



# OTHER COMPONENTS IN THE TUNNEL

---

- Joints
- Cable ducts
- Ventilator fixings



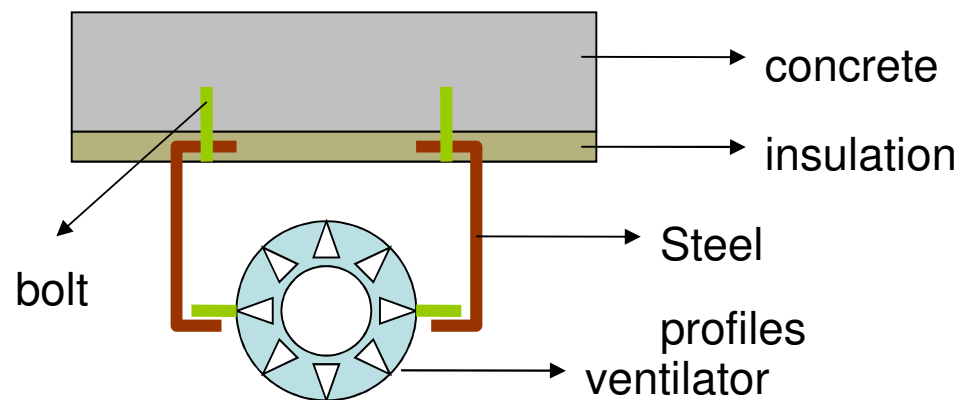
# VENTILATOR FIXINGS

---

## ❑ Structural detail: fixing of ventilator to tunnel ceiling

❑ Spalling of concrete

❑ RWS curve



# MOBILE FURNACE TESTS FOR EXISTING TUNNELS

---



# FACTORS AFFECTING THE RESULT OF A FIRE TEST

---

- ❑ FIRE CURVE
  
- ❑ COMPOSITION OF CONCRETE
  - Type of aggregate
  - Moisture content
  
- ❑ AGE
  
- ❑ LOADING, LOADING FRAME OR PRESTRESSING STRANDS
  
- ❑ PROTECTION
  - PP FIBRES
  - BOARDS
  - SPRAY MORTAR
  - COATING
  
- ❑ SIZE OF THE SPECIMEN



# CHALLENGES IN THE FUTURE

---

## ☐ New energy carriers

- Electric
- Hydrogen
- LPG
- CNG

## ☐ Challenges

- Battery
- Jet flame risk

29 October 2012,  
Wassenaar,  
Netherlands

*Presentation*



Figure 1: Bus on fire (left) and shooting flame. (Source: Regio15.nl)

# QUESTIONS

---

Contact:

Kamakshi Parwani

[kamakshi.parwani@efectis.com](mailto:kamakshi.parwani@efectis.com)

Tel: +31 88 3473 732

Mob: +31 6 25 08 48 62

