Statens vegvesen

Norwegian
Public Roads Administration

# Fire protection of tunnels
# - options and solutions

*Dr. Claus K. Larsen*

*Technology dep, Tunnel and concrete div.*

# Fatal catastrophic fires has increased the focus on fire safety in tunnels

## Fires in road tunnels

- Mont Blanc (F/I) 1999
  - 39 dead
  - 450 mill €
- Tauern (A) 1999
  - 12 dead
  - 50 mill €
- St. Gotthard (CH) 2001
  - 11 dead
  - ??? mill €

## Fires in train tunnels

- King's Cross (GB) 1987
  - 31 dead
  - ??? mill €
- Baku (AZE) 1995
  - 289 dead
  - ??? mill €
- Eurotunnel (F/GB) 1996
  - 0 dead
  - 450 mill €
- Kaprun (A) 2000
  - 155 dead
  - 1.5 mill €/month

16. juli 2000
Uke 28
Kr. 10,00

WWW.VG.NO

MYHRE KRASJET på vei til bryllup
• SIDE 7

Jeg er på JAKT
• SIDE 46 og 47

250 tunneler kan være DØDS-FELLER

Frykten for nye branner brer seg etter katastrofen i Seljestadtunnelen (bildet). Det finnes over 250 brannfarlige tunne-

NRK Hordaland

# Vogntog tok fyr i tunnel

Svandalsflonatunnelen på E134 mellom Røldal og Haukeligrend var stengt i flere timer etter at et vogntog tok fyr.

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Av Kristina Brekke og Ingvil Teige Stiegler

Brannen ble slukket, men opprydningsarbeidet tok flere timer.

Vogntoget som tok fyr var lastet med fisk.

## Tankbil med gass

- En tankbil lastet med gass står i Røldals-enden av tunnelen. Men den står såpass langt borte at den ikke representerer noen umiddelbar fare, fortalte operasjonsleder Sven Bruarøy ved Hordaland politidistrikt mens det fremdeles brant.

Politiet fikk melding om brannen like etter klokken halv ti.

# There are obvious reasons to protect tunnels – but how?

| Fire load | < | Fire resistance |
|---|---|---|

**Fire load**

- Fire size?
- Duration?
- Fire spread?
- Standards and codes?
- Experience?
- Testing methods?
- ...

**Fire resistance**

- Structural design?
- Choice of materials?
- pp-fibers?
- External fire protection?
- Extinguishing systems?
- Fire suppression systems?
- ...

Type of tunnel (rock, cut and cover, immersed, floating, ...)

Amount and type of traffic (%HGV, %DGV)

Ventilation

Technical equipment

Consequences for people and economy

# How are real fires represented as “numbers” for design of fire protection?

- How much heat that is released per unit time (Heat Release Rate): HRR in xx MW
  - Cars ~5MW
  - Buses ~20MW
  - Trucks ~30-100MW
  - Tankers ~300MW
- Maximum temperature
- Duration of the fire

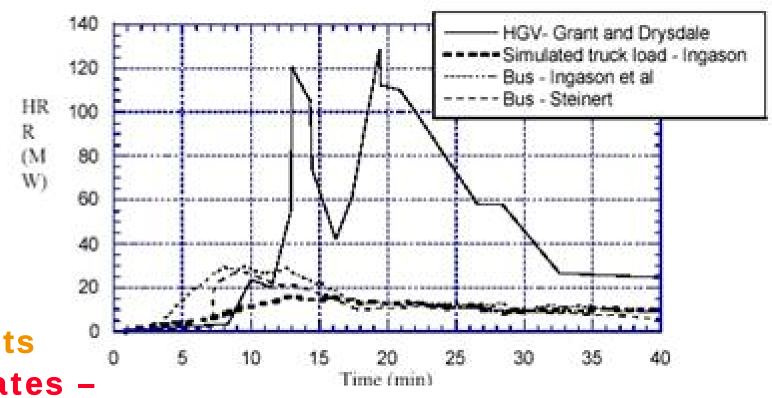
Measurements

Few measurements - estimates

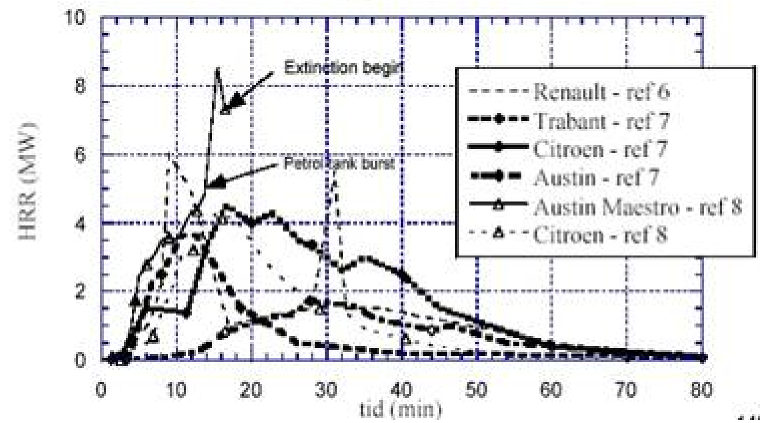
Only estimates – based on small scale tests

**Time-temperature curves**

Truck and bus fires

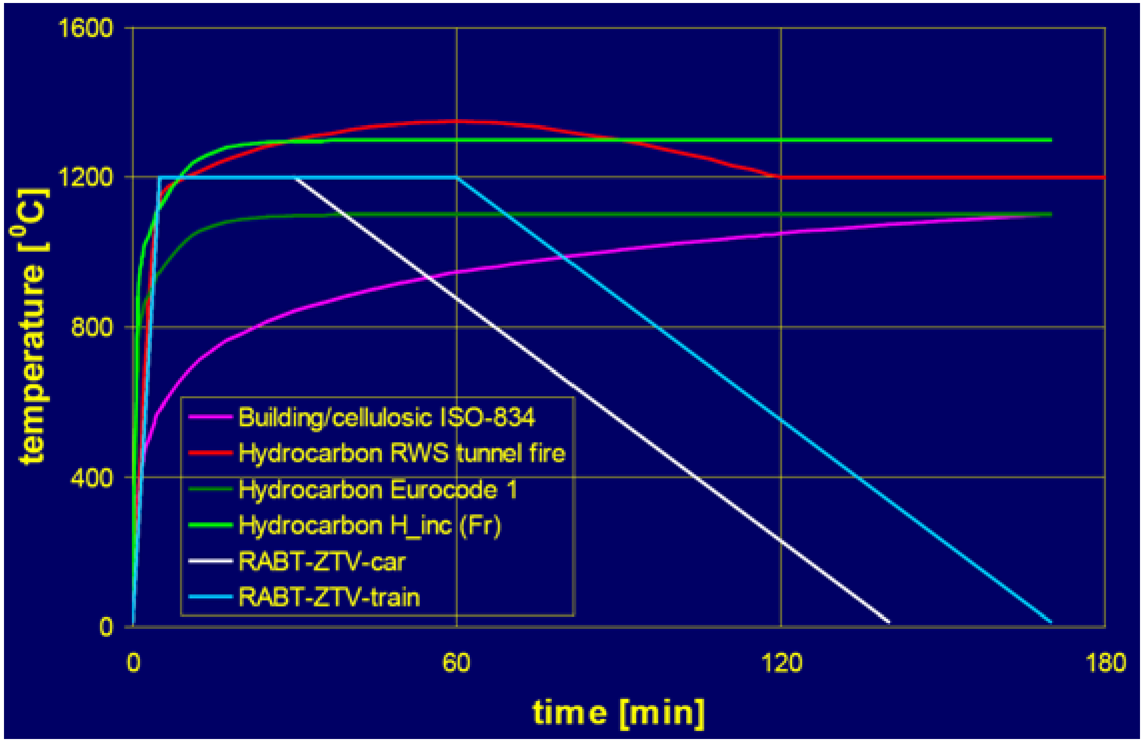



Car fires



# Commonly used time-temperature curves

- Standard ISO 834
  - max 1030°C @2hrs
- Hydrocarbon (HC)
  - max 1100°C @20min-2hrs
- RABT/ZTV
  - max 1200°C @10-30min
- MHC
  - max 1300°C @20min-2hrs
- RWS
  - max 1350°C @1hr

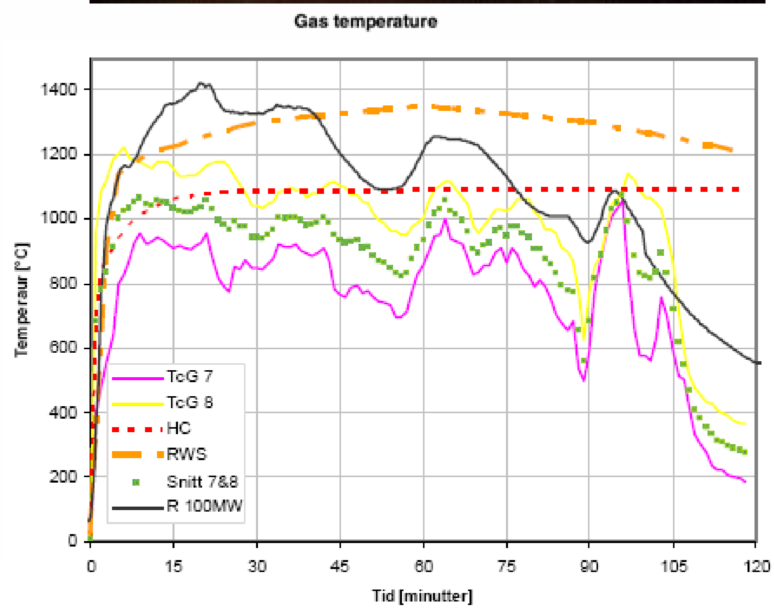



K. Both, efectis

# What about experience with real scale fires or full scale fire tests?

- The UPTUN fire test in Runehamar Test Tunnel in 2003 clearly showed much higher HRR and gas temperatures than expected from normal HGV-goods
  - RWS-like temperatures
  - Up to 200MW
  - Fire can spread to vehicles 100m downstream

- Recent full scale tests performed by NPRA in Runehamar Test Tunnel showed that a small tanker-sized pool (11.000 liters diesel; 40m$^2$) yields very high gas temperatures
  - Up to (more than?) 1400 °C
  - The ventilation was controlled by the fire

| Fire category | Heat Release Rates [MW] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Recommendations by institutions[1] | | | | | Fire tests | | | | |
| | PIARC 1987 | PIARC 1999 | RABT (D) 1994[7] | CETU (F) Proposals[2] 1996/1997 | NFPA 502 *(USA)* *1998* | EUREKA research: real fires[3] | EUREKA research: report Ingarson[6] | Runehamar | Memorial: adopted fire sizes | Estimates from large accidents[6] |
| Passenger car | 5 | | --- | 2.5 | *5* | 1.5-2[4] | | --- | --- | |
| Passenger car (large) | --- | | --- | 5 | --- | --- | | --- | --- | |
| passenger van (plastic) | --- | 2.5-8 | --- | --- | --- | 5-6[5] | 2.5-9 | --- | --- | 3-10 |
| 1 – 2 passenger cars | --- | | 5 - 10 | --- | --- | --- | | --- | --- | |
| 2 – 3 passenger cars | --- | | --- | 8 | --- | --- | | --- | --- | |
| 1 van | --- | 15 | --- | 15 | --- | --- | --- | --- | --- | --- |
| 1 public bus | --- | 20 | --- | --- | --- | 29-34[5] | 29-34 | --- | --- | 36 |
| 1 bus or 1 lorry (freight of lorry not hazardous) | 20 | --- | 20 - 30 | 20 | *20* | --- | --- | --- | 20 | --- |
| heavy goods vehicle | --- | --- | --- | 30 | --- | 100-130[5] | 128 | --- | --- | 150-400 |
| petrol/gasoline tanker with a leak | 100 | 100 | 50 - 100 | 200 | *100* | --- | 20-100 | --- | --- | 120-300 |
| flammable spill of 400 liters | --- | --- | --- | --- | --- | --- | --- | --- | 50 | --- |
| flammable spillof 800 liters or hazardous material | --- | --- | --- | --- | --- | --- | --- | --- | 100 | --- |
| mixed load, 2844 kg, (wood, rubber tyres, plastic material) | --- | --- | --- | --- | --- | 15-17[5] | --- | --- | --- | --- |
| different HGV loads | --- | --- | --- | --- | --- | --- | --- | 71-223 | --- | --- |
| carriage | --- | --- | --- | --- | --- | --- | 12-47 | --- | --- | 3-100 |

1): Dutch recommendations: see table 3.1/8

2): proposals are related to special types of road tunnels (e. g. with height clearance for passenger cars only, see table 3.1/9)

3): energy contents between approx. 3 GJ (passenger car) and approx. 90 GJ (heavy goods vehicle)

4): 3 fire tests done in Lappeenranta, Finland

5): values depend on the measuring system and on the method of data evaluation

6) Report Ingarson: [104]

7) New issue from 2003 [52] recommends fire loads for lorries only, depending on traffic:
- 30 MW if (lorries x km) / (day x table) ≤ 4000

# Design fires, Directives and codes – do they provide any answers?

- Full-scale fire tests (HGV and small-tanker) have proven to be very severe
  - Indications that RWS is not very conservative
  - Real fires (estimated) to larger than design fires

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- **DIRECTIVE 2004/54/EC**:

  2.7. Fire resistance of structures

  The main structure of all tunnels where a local collapse of the structure could have catastrophic consequences, e.g. <u>immersed tunnels</u> or <u>tunnels which can cause the collapse of important neighboring structures</u>, shall ensure a **sufficient level of fire resistance**....

No indication of fire loads...

No indication of what sufficient fire resistance is...

- **EN 1992-1-2:2004 Eurocode 2 - Structural fire design**
  - avoid collapse of the structure
  - Valid “only” for ISO and HC fires
  - Calculation models must be verified by fire tests for RWS, RABT, MHC...
  - All relevant material data must be verified by fire tests for RWS, RABT, MHC...

No indication of fire loads for tunnels...

No standardized solutions or methods for the most severe fires...

# Fire load on the walls must also be considered carefully – not only the roof!

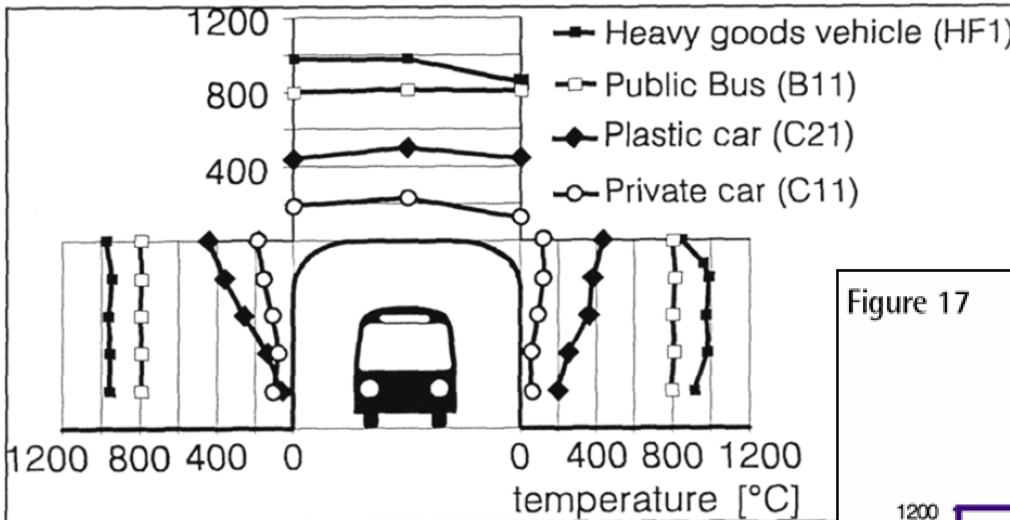
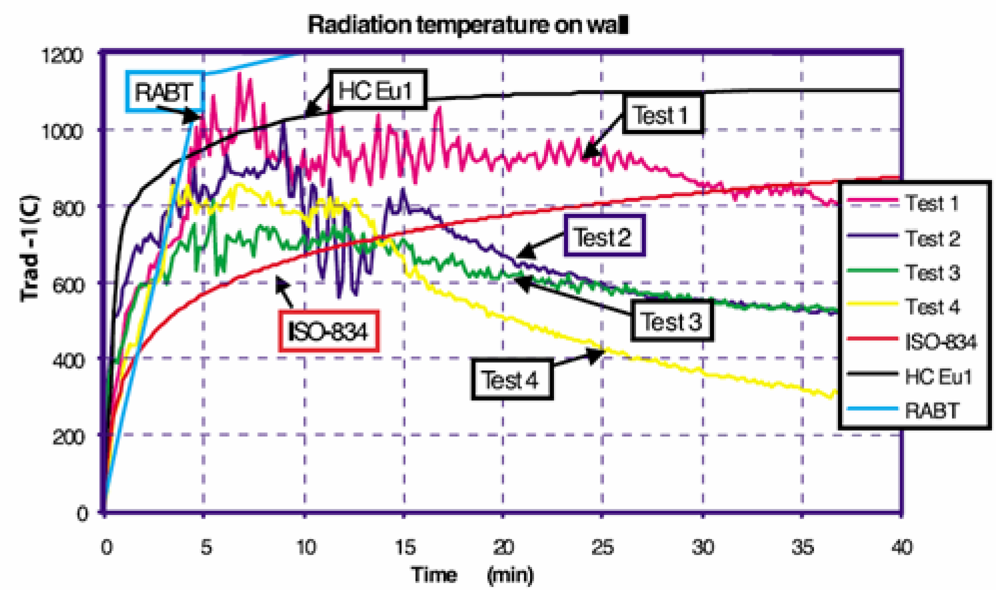


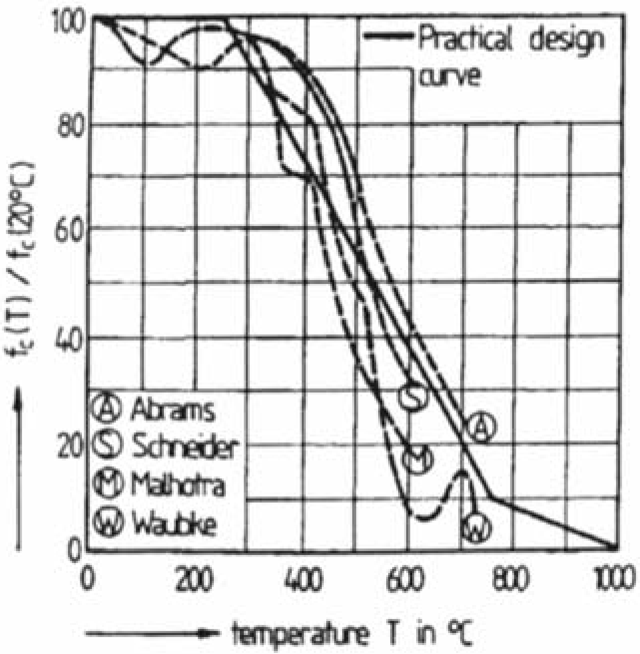

Figure 17 Radiation temperatures on the wall 1m above the floor for all tests.

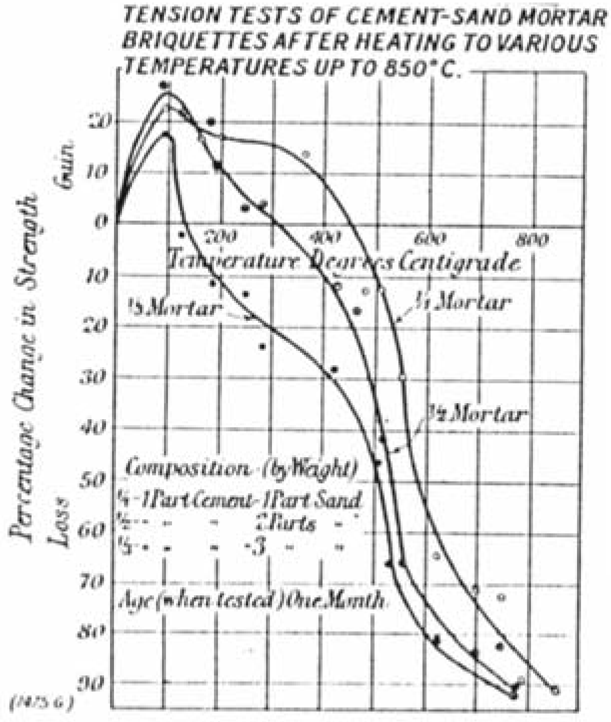


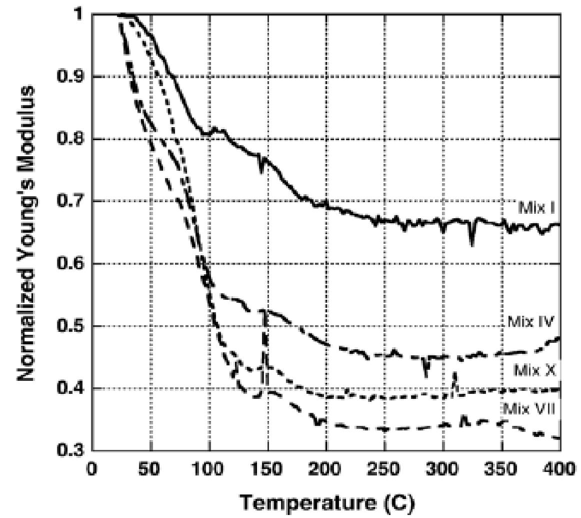
# It is critical to avoid spalling

- Explosive spalling is the most severe form of spalling
- Spalling can expose the reinforcement to high temperatures
- Spalling can reduce the load carrying capacity
- Spalling can lead to leakage of water (critical for immersed tunnels)
- Spalling can ultimately lead to a collapse of the structure

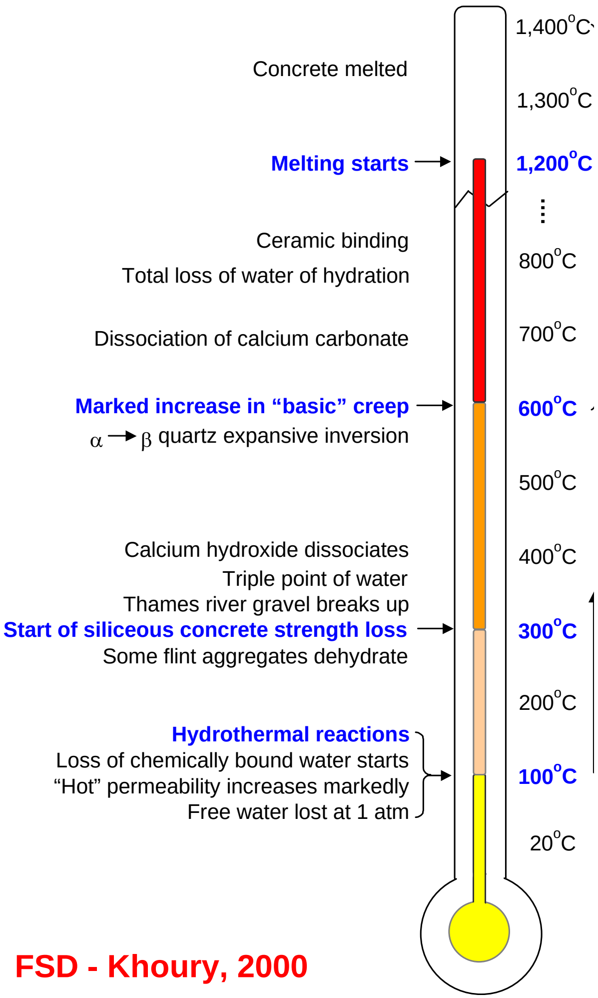
# Concrete looses strength and stiffness fast above 300°C



# Ultimately concrete melts above ~1200°C




**FSD - Khoury, 2000**

SV-40 concrete started to melt after the FP failed

# Options for passive fire protection of concrete

## Improving the spalling resistance of concrete

- PP-fibers (type and amount !!)
- Steel fibers (type and amount !!)
- Aggregate (heat cap. and expansion)
- Porosity (the higher the better)
- Moisture (the lower the better)

## External fire protection as thermal barrier

- Protecting the concrete from strength loss
- Protecting the reinforcement
  - Sprayed systems
  - Board systems

Temperature requirements

Spalling requirements

Durability requirements

Traffic load (anchoring, bond-strength, fatigue, ...)

Aesthetics, surface finish, maintenance

Easy replacement in case of damage

# PP-fibers are no guarantee for fire proofing!


**PP-fibers do not improve the thermal properties of concrete**

**PP-fiber concrete looses strength the same way as ordinary concrete**

# Some examples of fire protection of tunnels

- **Holmsdale Tunnel, M25, London**
  - AADT 110,000; 6 lanes; divided traffic
  - Concrete; cut and cover; buildings on top
  - RWS; 200°C criteria for roof beams
  - ➢ Cafco Fendolite MII (sprayed system) with mesh-reinforcement for roof beams

- **Clyde Tunnel; Glasgow**
  - Bored; under river; cast iron segments
  - RWS; vibrations; curvature
  - ➢ Promat Promatect-T (board system) with coated steel sheeting

# Fire protection of the Immersed Bjørvika Tunnel

- 300MW/RWS fire curve as design fire
- Development of a new test method for fire protection of concrete in RWS fire
- Both PP-fibers and thermal barrier
- Strict requirements for the external fire protection
- All systems must be mechanically anchored to the structural concrete

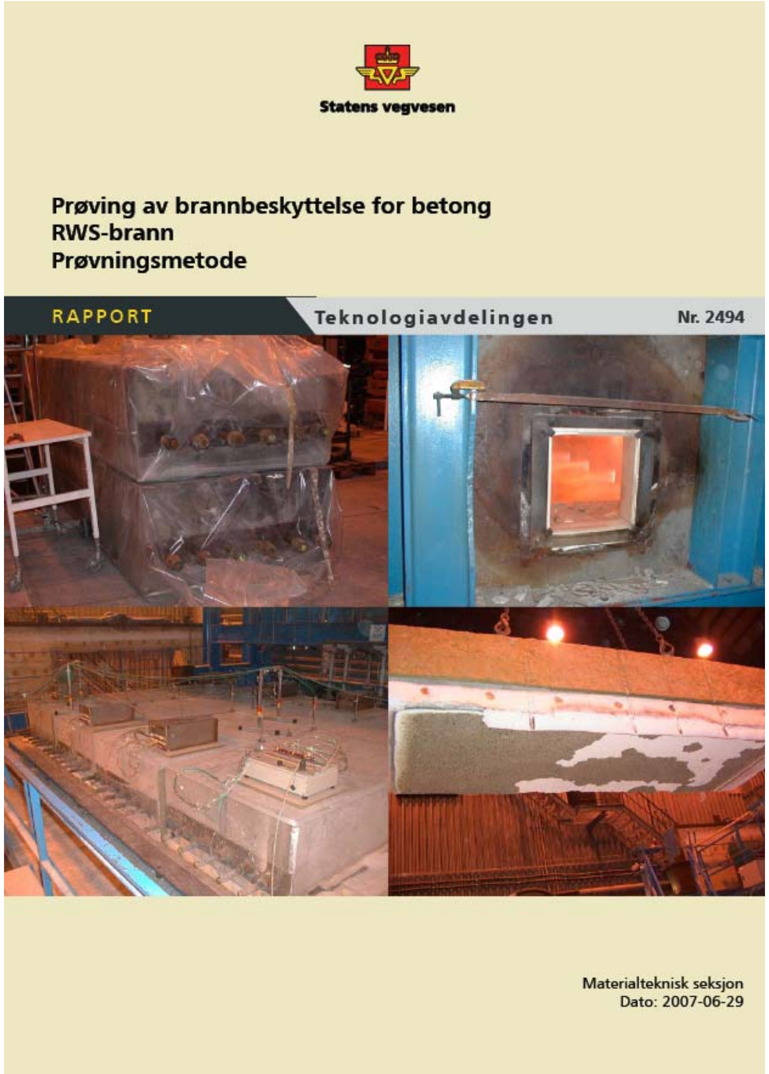
➢ Tender for roof/upper part of walls – dead-line August 2008

➢ Tender for outer walls scheduled for publication late summer 2008

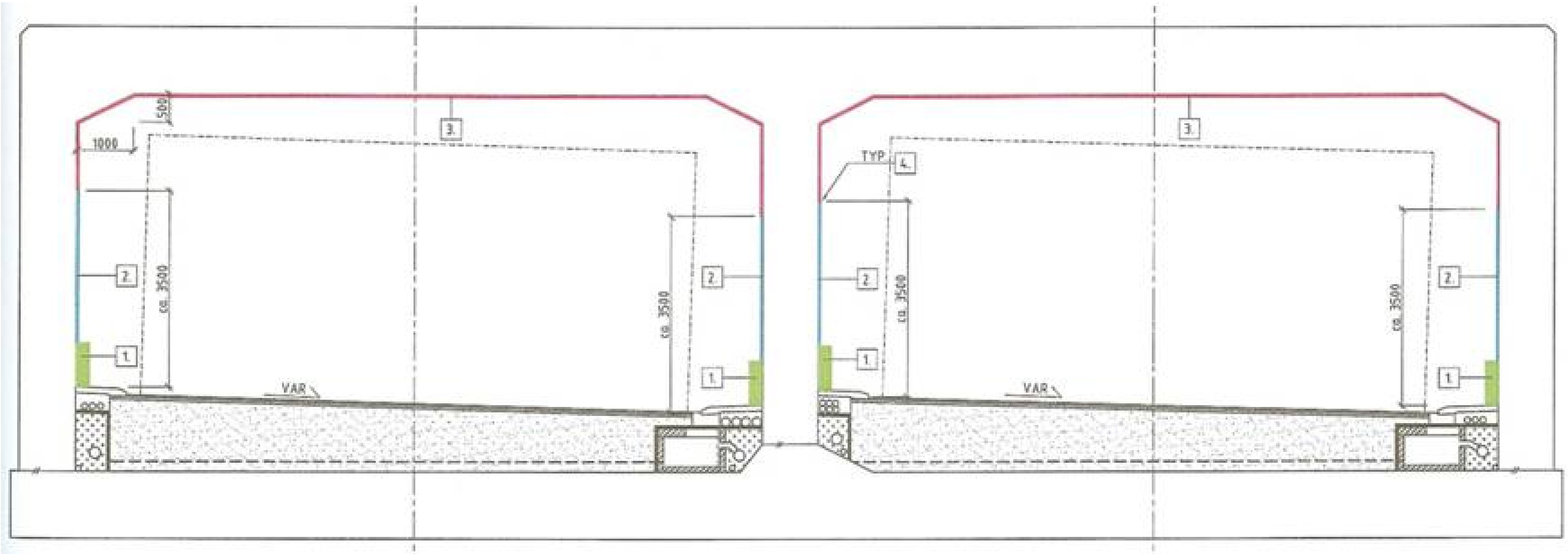
❖ Estimated cost 8-10 mill €

# Fire protection of the Immersed Bjørvika Tunnel – new test method

- Development of our own test method for fire protection of concrete in RWS
  - Based on fire testing of large concrete elements
  - RWS-proven systems failed in the larger scale test
- Compressive stress of 11 MPa
- High quality concrete (m=0.40, B55)
- Sealed curing, min. 3 months old
- Relatively large test elements ($1.2 \times 3.6 \times 0.6\ m^3$)
- Sprayed systems must be anchored with stainless steel mesh and bolts
- Board systems must have at least two joints
- 16 TCs for temperature at interface and at reinforcement



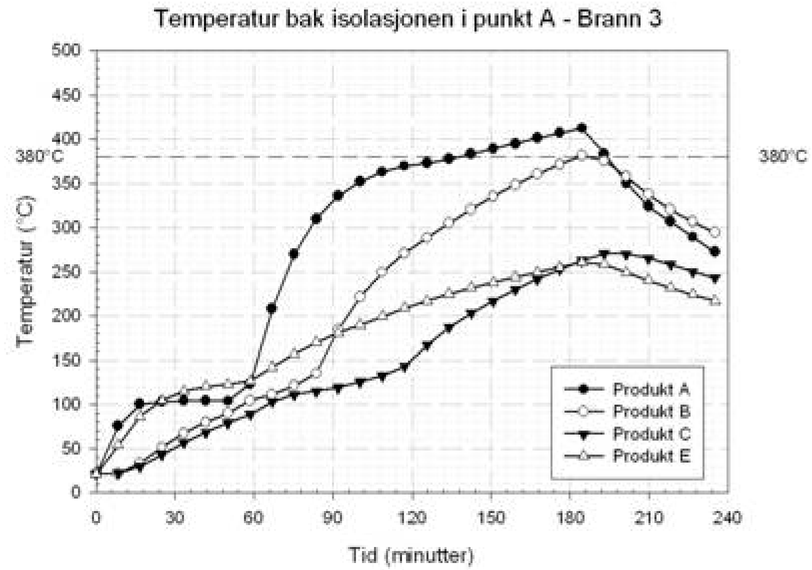
# Fire protection of the Immersed Bjørvika Tunnel – concept of structural FP

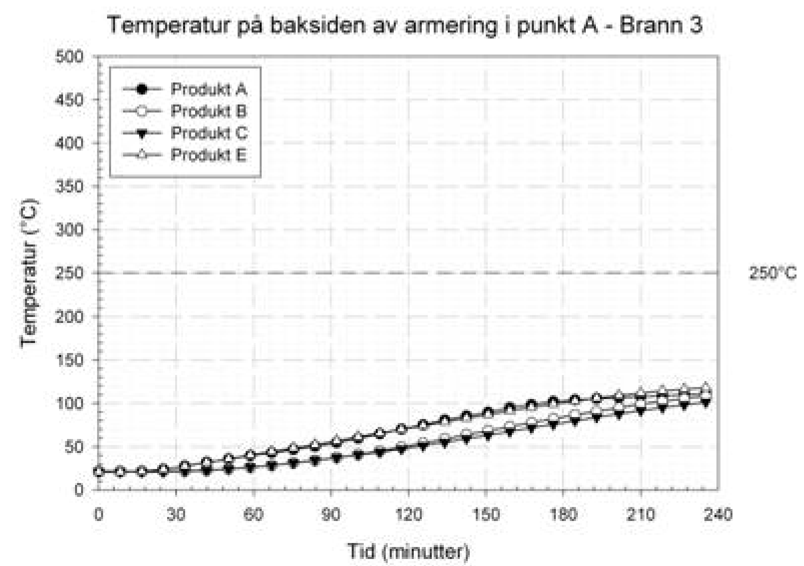



- PP-fibers in the roof (lowest part, 30-40cm); $2kg/m^3$, 18um-6mm
- External fire protection on the roof and upper part of all walls; sprayed or boards; anchoring
- Sacrificial concrete wall element in outer walls (yet to be tested and verified)
- Calculation and measurements of temperature profile through sacrificial wall and in joints
- Special care taken at element and segment joints (movement) – protect rubber gaskets and water-stop

# Fire protection of the Immersed Bjørvika Tunnel – strict requirements for FP

- Documentation acc. to TR no. 2494
- Fire resistance requirements
  - No spalling during/after tests
  - Interfacial temperature < 380°C
  - Reinforcement temp. < 250°C
  - No systems must fall off during/after tests
- All parts must be non-combustible
- Sprayed systems must be anchored with stainless steel mesh and bolts
- Board systems must use stainless steel fixings
- Durability: carbonation, freeze/thaw, alkali-resistance
- Resistance against tunnel wash-down
- Fatigue; 150mill cycles;




Statens vegvesen

Norwegian Public Roads Administration

# Summary

- Design fires for tunnels may not be conservative and they are not regulated in directives or standards
- No standards covering testing of fire protection of tunnels
- No standards or codes that give straight-forward solutions in case of RWS or similar large fire scenarios
- When collapse must be avoided a combination of PP-fibers and a thermal barrier is required
- Large fires require protection of roof and walls from top to bottom
- Pay attention to details!

**Thank you for your attention!**

claus.larsen@vegvesen.no