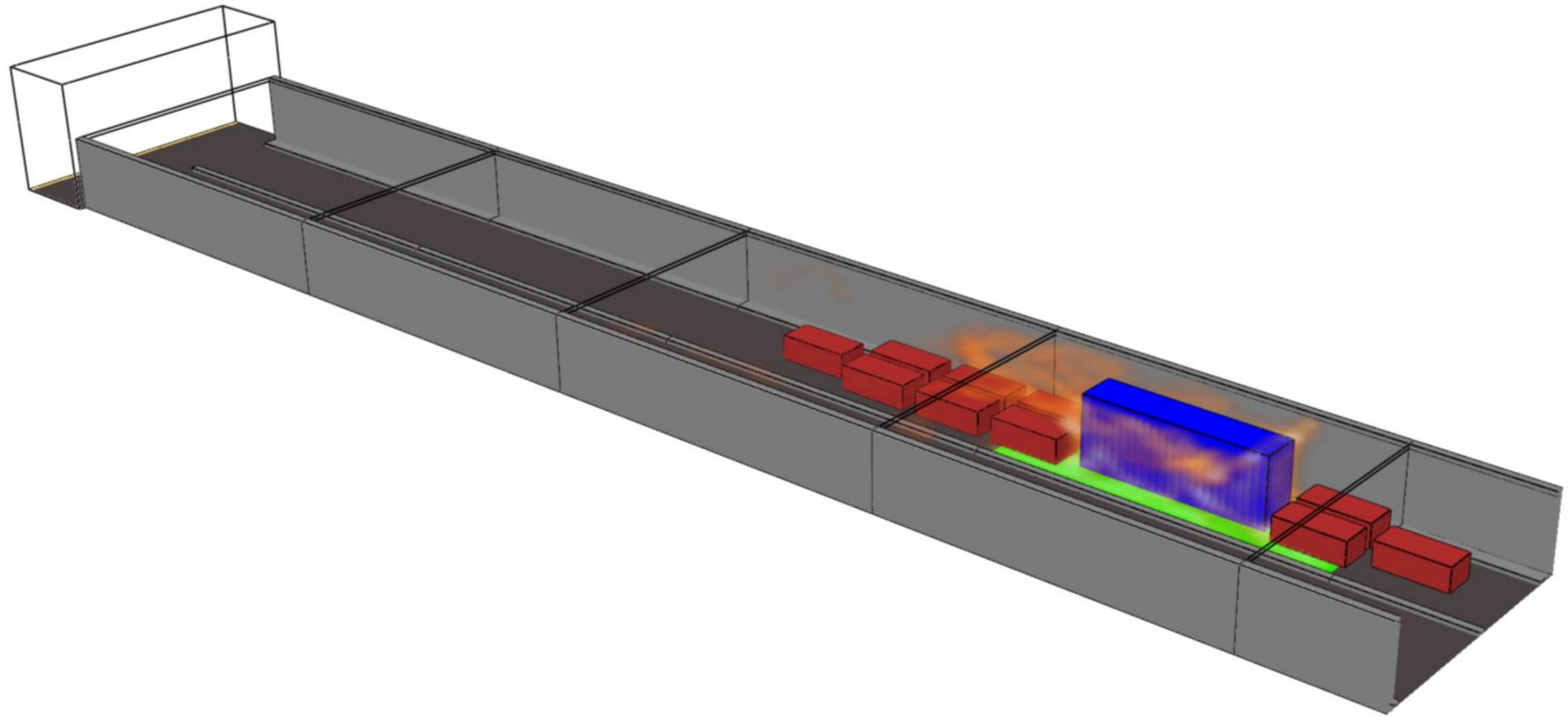
Structural fire assessment of an existing tunnel

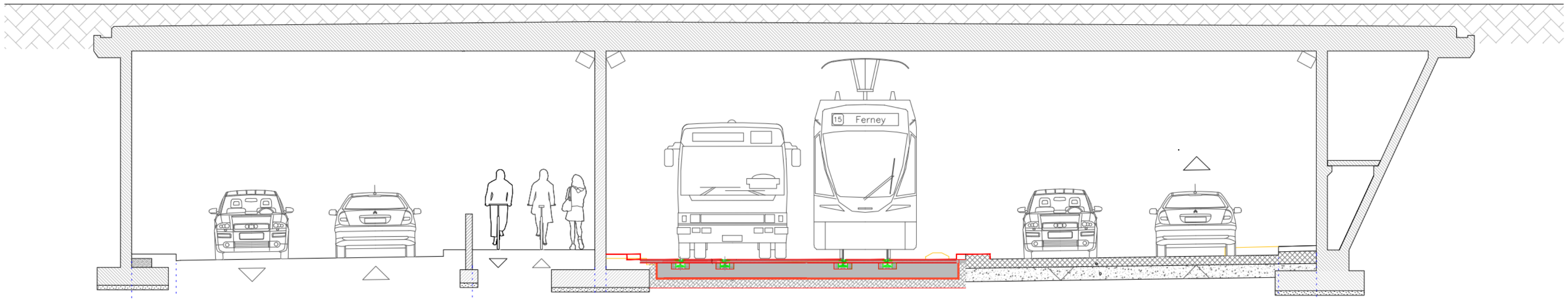
Eric Tonicello & Julien Duboc – ISI Sàrl – Lausanne, Switzerland



Description of the project

Transformation of an existing tunnel

- Road tunnel under the Geneva Airport
- Transformation in the remit of a tramway project
- Check the **fire safety** :
  - ✓ Evacuation
  - ✓ **Structural fire resistance**



Fire resistance requirements

In Switzerland, no explicit fire duration requirement for tunnel structures

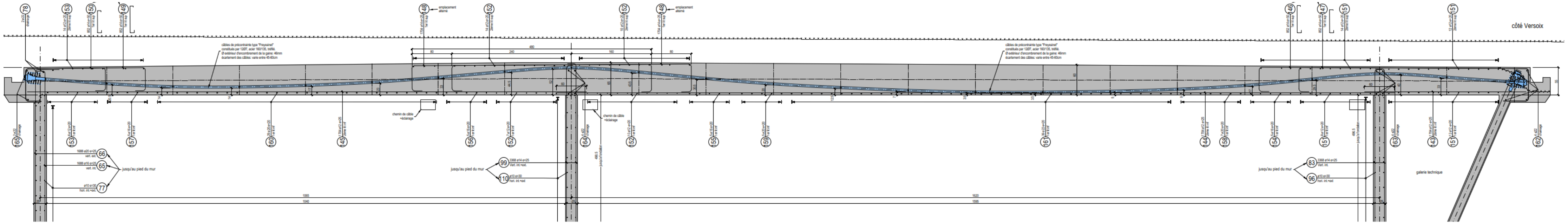
- **Objective:** Get enough time to people escape in safe conditions
  - **R60** as a minimum (sometimes 90 min.)

- **Requirements for this specific tunnel:**
  - Ensure **safe evacuation**
  - **No structural collapse** : Taxiway & Runway
  - No significant deformations

Structure of the tunnel

Prestressed concrete structure

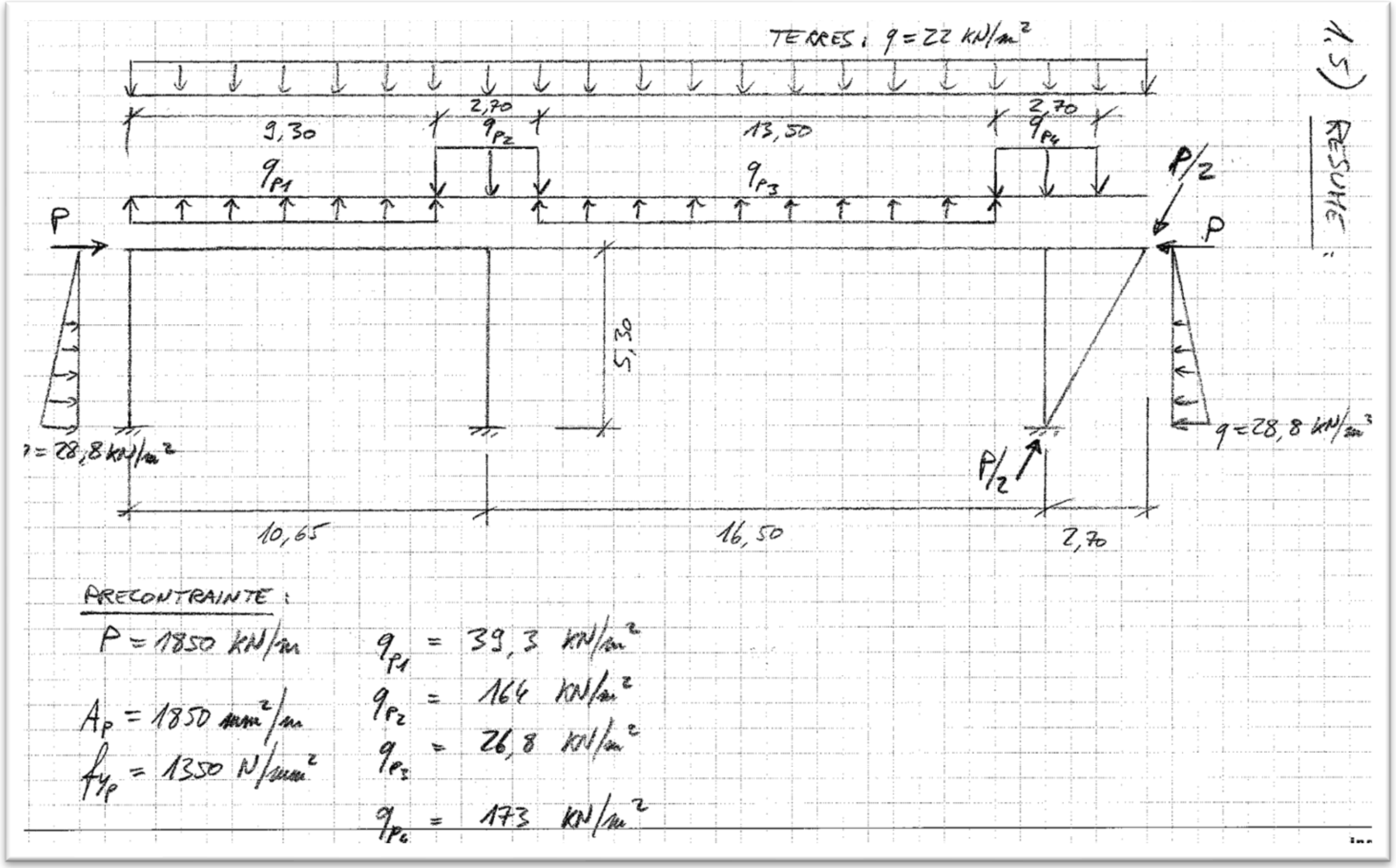
- The main structure consists of a double span slab, supported by RC walls
- **~100 %** prestressed-based design on the transversal direction



Structure of the tunnel

Prestressed concrete structure - design

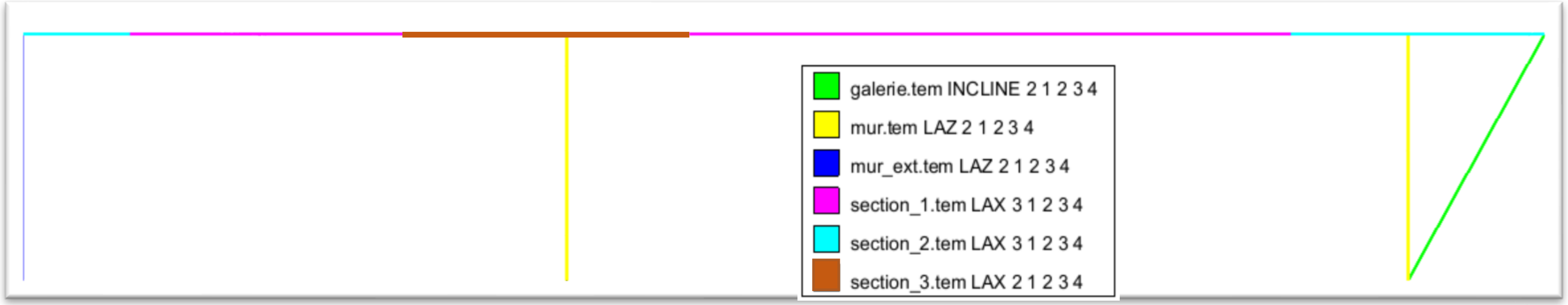
- Substitute forces to consider prestressed cables
  - q_{p1}, q_{p2}, q_{p3} and q_{p4}

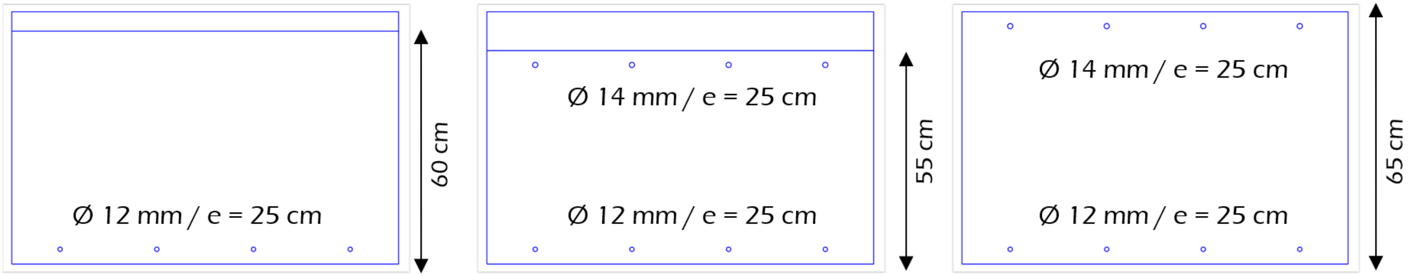


Structure of the tunnel

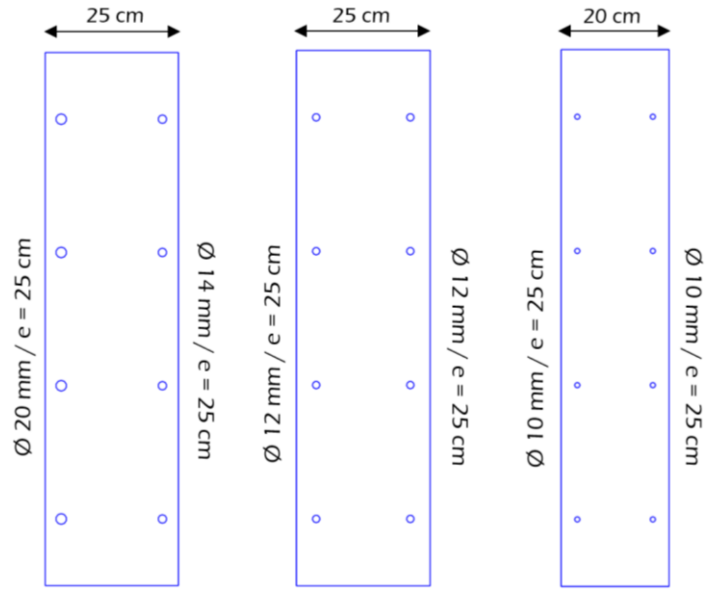
Different sections

- 3 sections for the slab
- 3 sections for the walls
- «Few» rebars
- **Mainly prestressings cables**





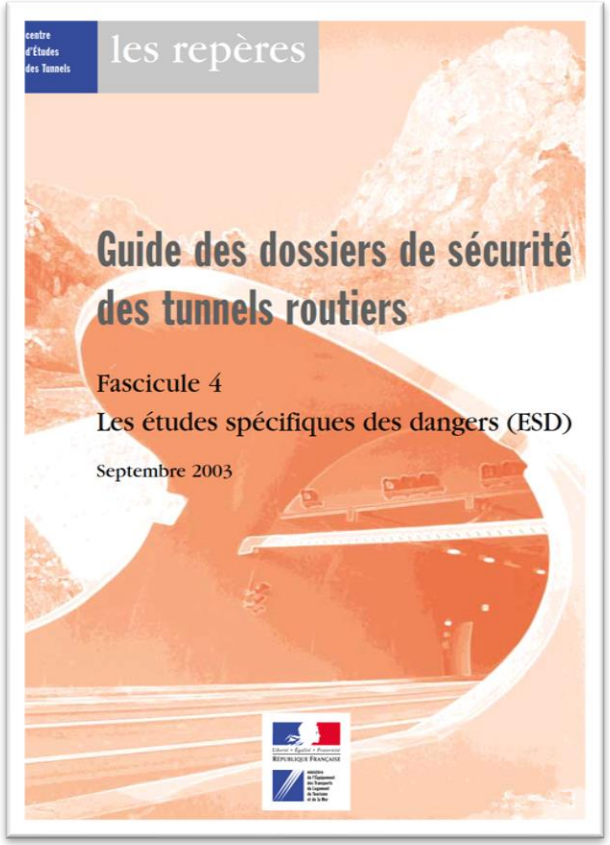
Section_1 Section_2 Section_3

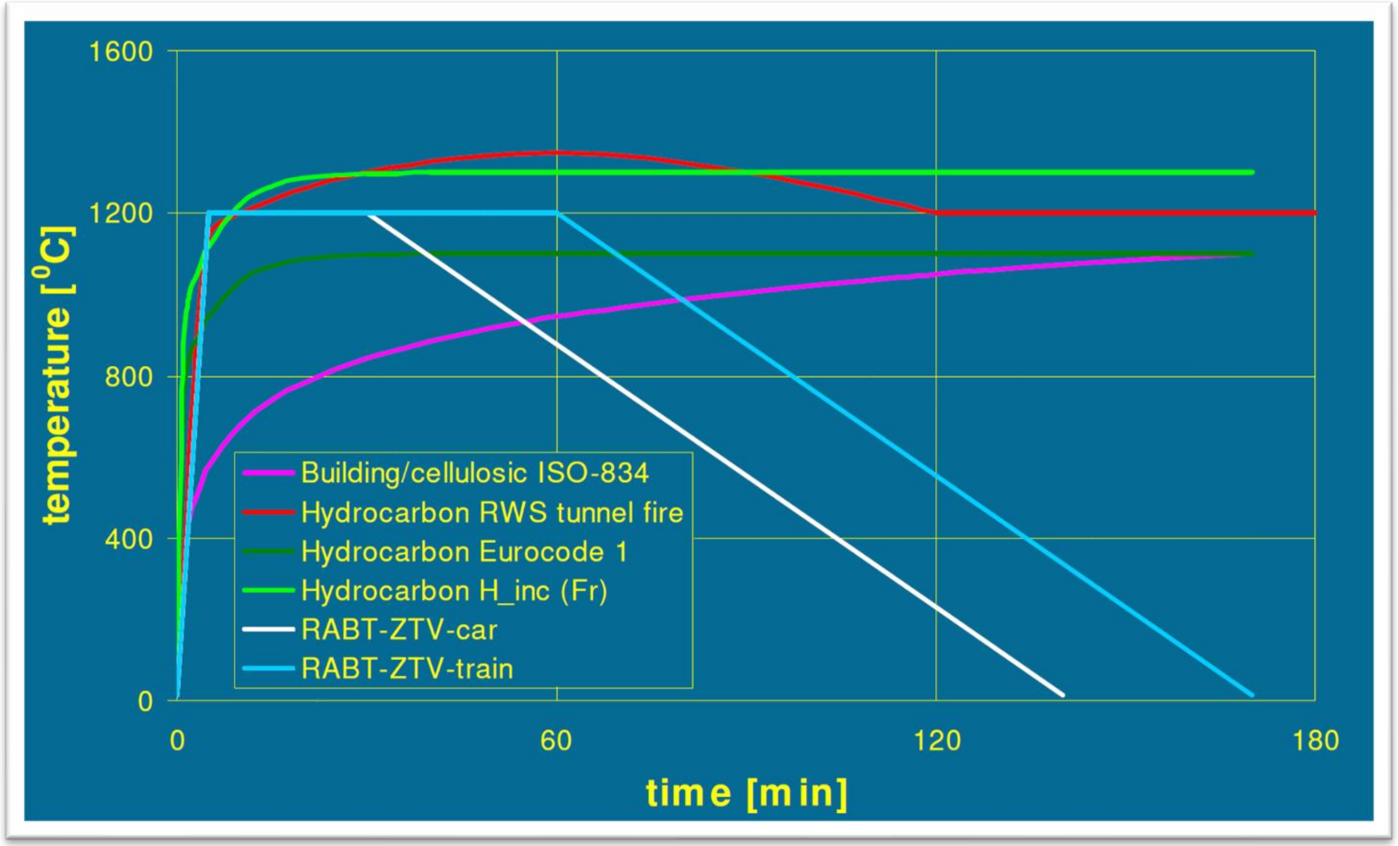


Wall ext Central wall Gallery

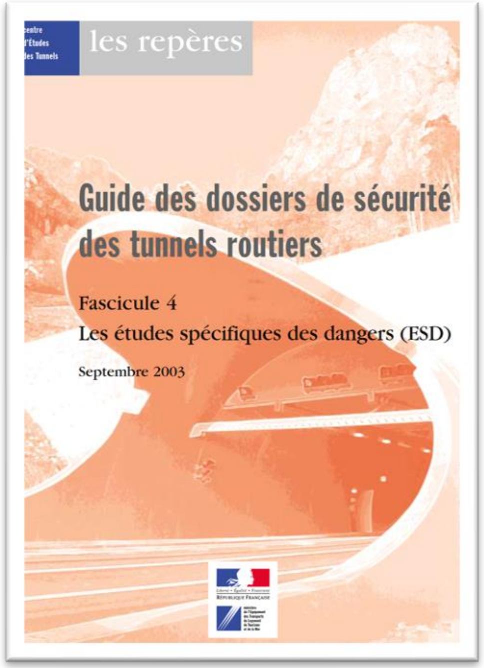
PBD approach – Step 1 : standard curves

- **RWS** and **ISO** fire curves

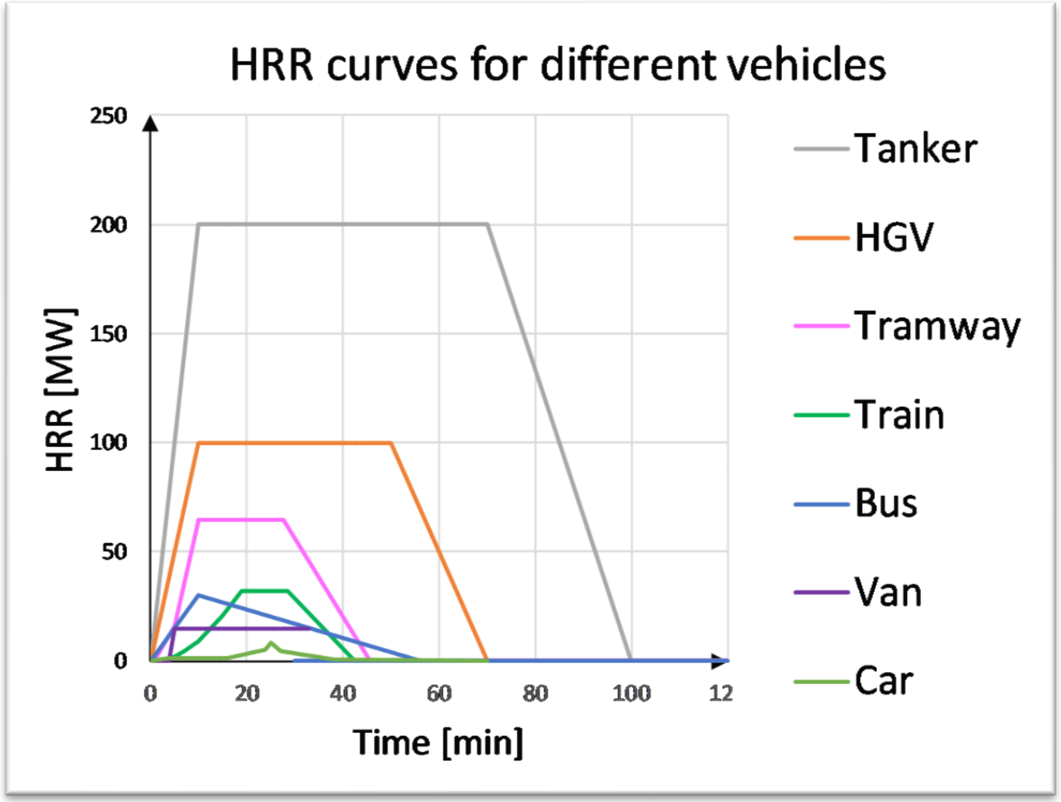




PBD approach – Step 2: natural fire scenarios



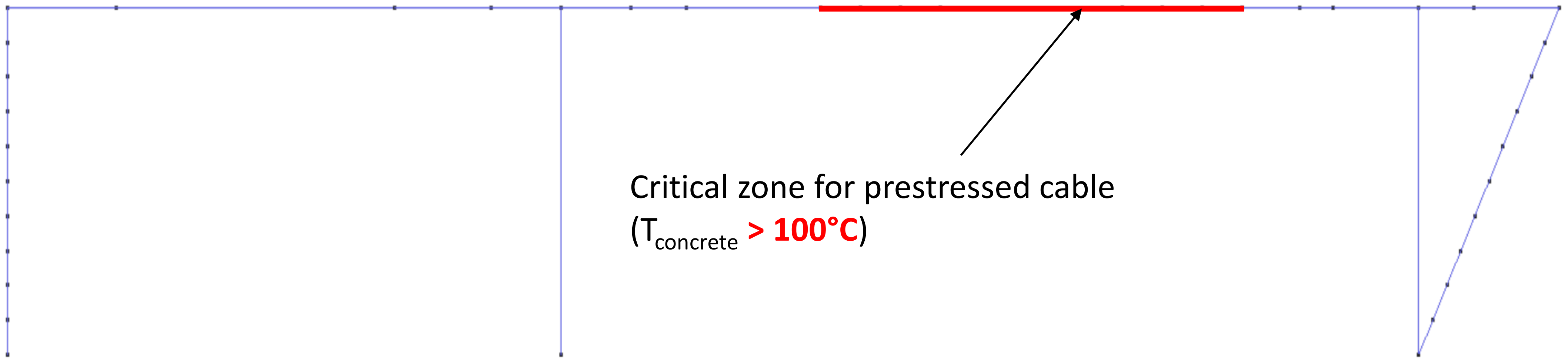
- ✓ Heavy Goods Vehicle fire
- ✓ Fuel tanker fire
- ✓ Tramway fire



PBD approach – Standard fire curves

Thermal calculations

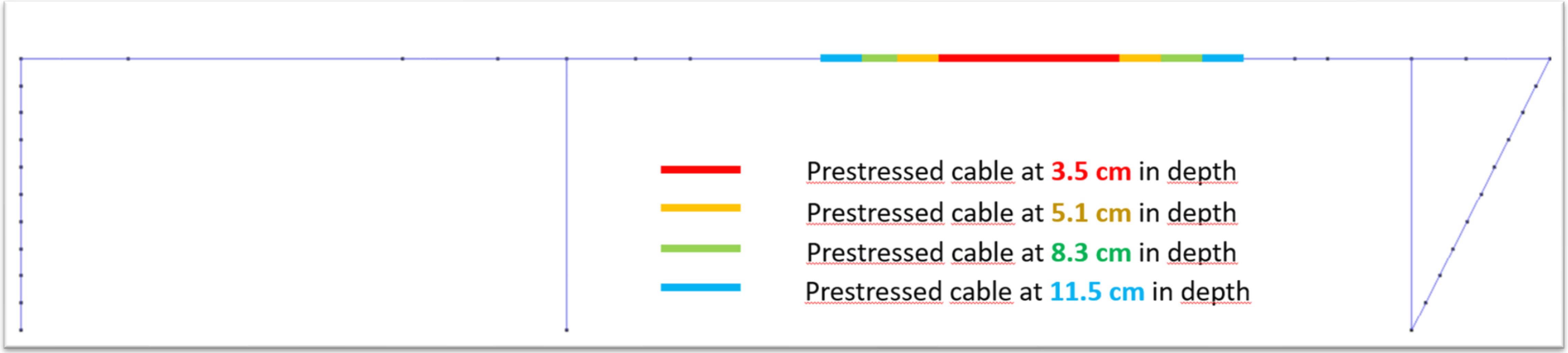
- Check the sensibility of the heating of the prestressing cables



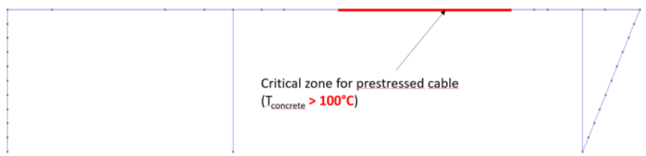
PBD approach – Checking the prestressing

Thermal calculations

- Check the sensibility of the heating of the prestressing cables

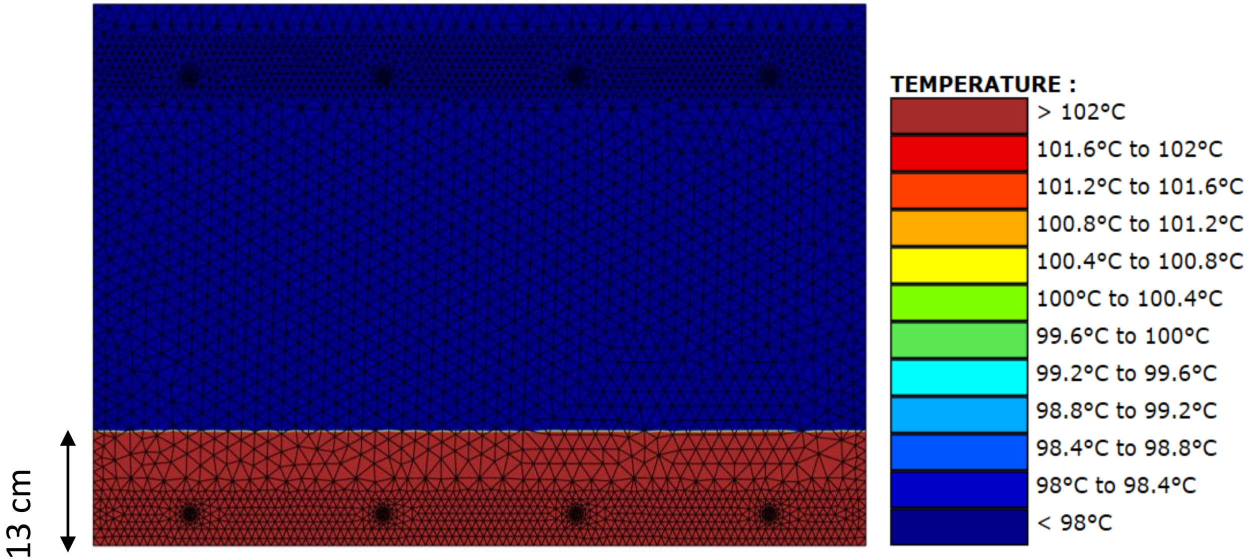


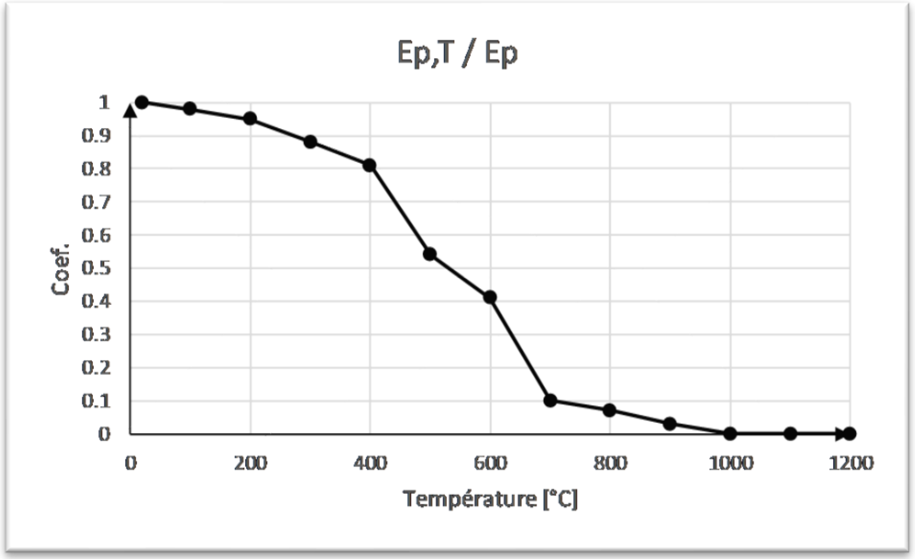
PBD approach – Standard fire curves



Thermal calculations

- Temperature evolution in concrete and rebars
- 2D and 3D FEM calculation with SAFIR



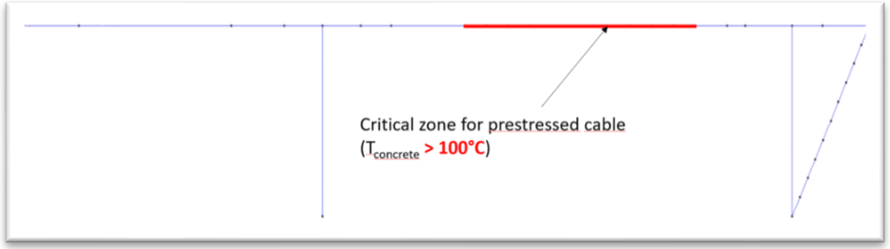


Evolution of Young modulus of prestressed cable in function of temperature

PBD approach – Standard fire curves

Thermal calculations

- Temperature evolution in concrete and rebars
- 2D and 3D FEM calculation with SAFIR



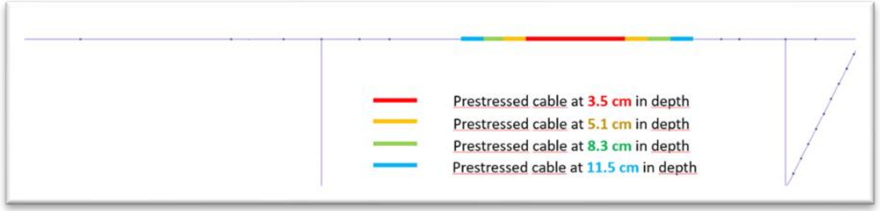
Loss of «substitute forces» due to temperature

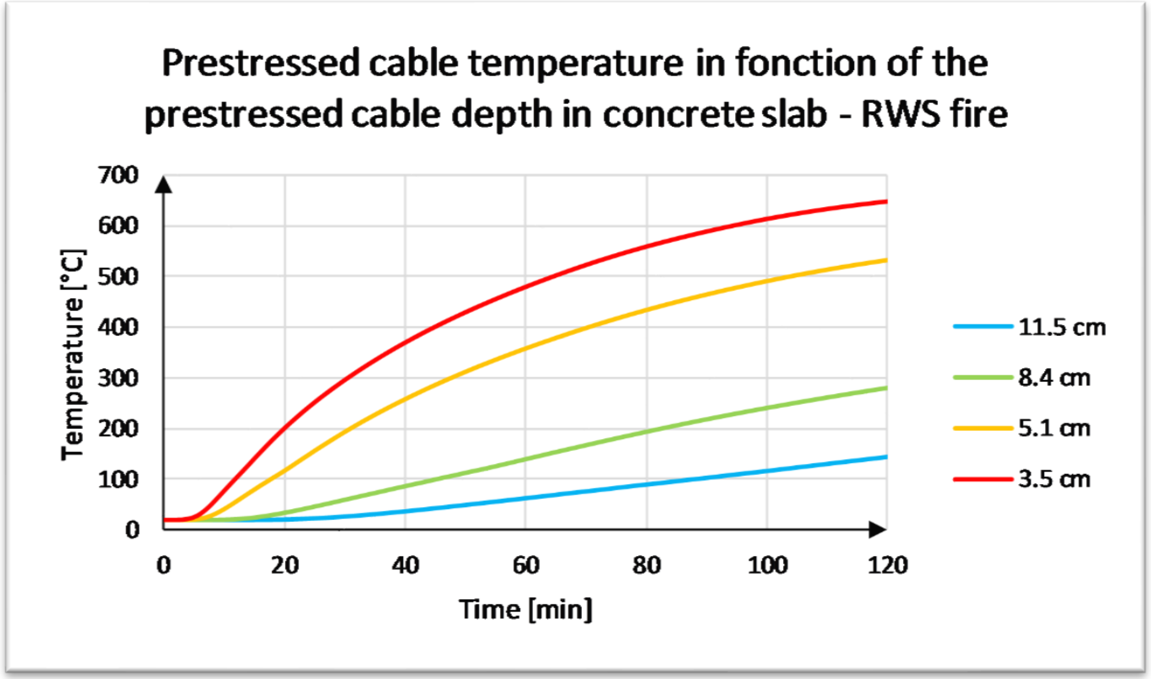
- Thermal elongation
  - ✓ $L_{i+1} = \alpha\, L_i\, (T_{i+1} - T_i) + L_i$

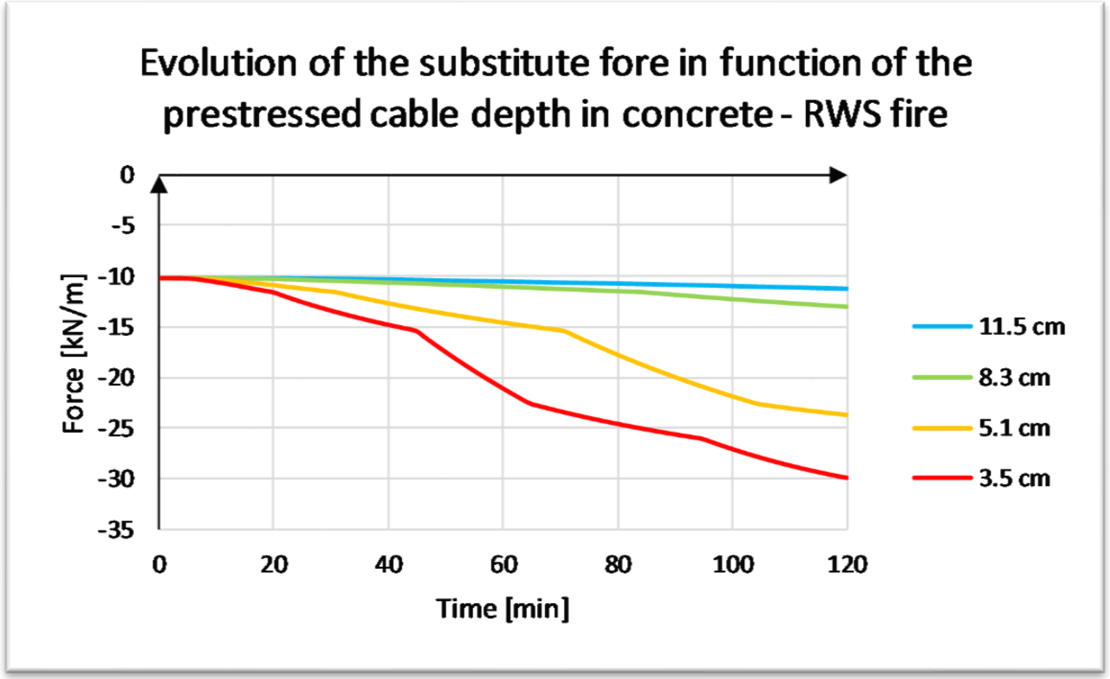
- Young modulus reduction
  - ✓ Up to 13 cm in concrete

PBD approach – Standard fire curves

Thermal calculations







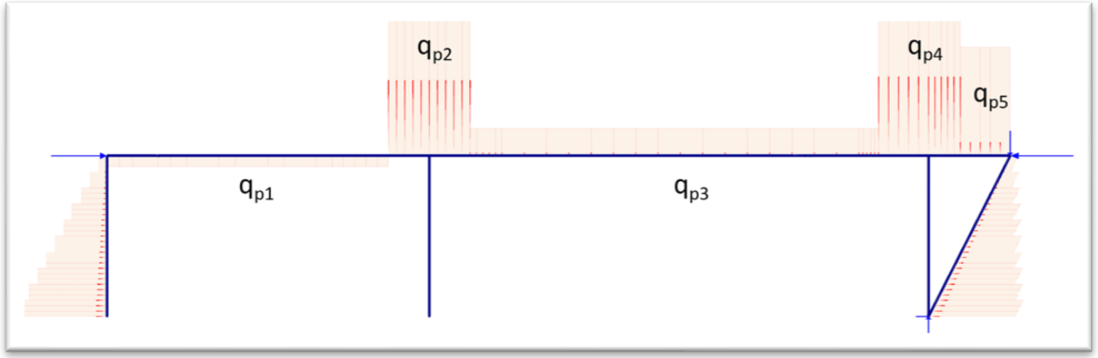
PBD approach – Standard fire curves

Structural calculations

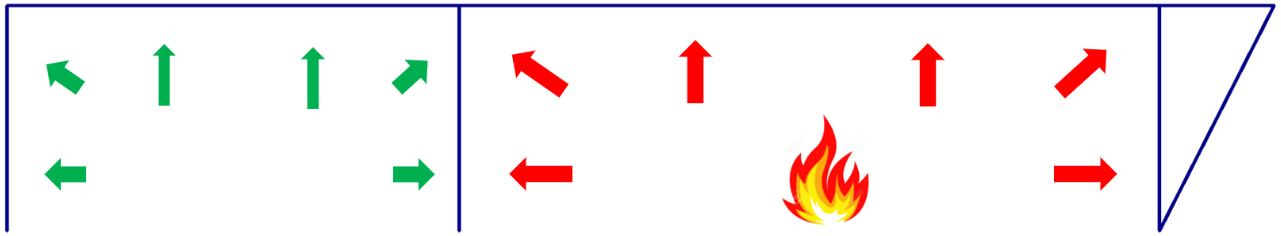
- FEM calculation with **SAFIR®**

- Structural model with beam elements

- Loading conditions in function of temperature
  - According to thermal calculations



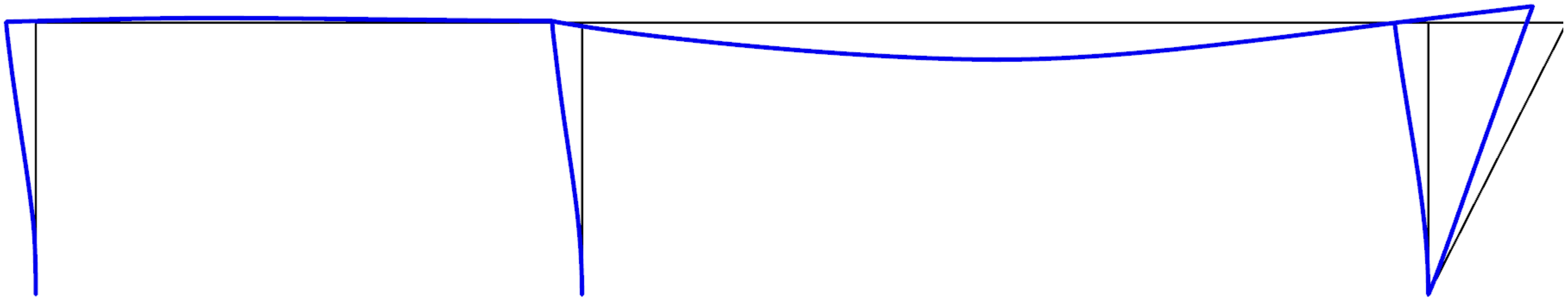
- Fire scenario in the right section :



PBD approach – Standard fire curves

Structural calculations

- FEM calculation with SAFIR

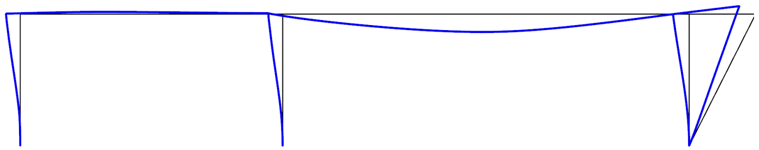


Structural FEM model: initial state (black) / deformed state (blue)

PBD approach – Standard fire curves

Structural calculations

- FEM calculation with SAFIR



- Pre-stress concrete structure < R60

- High deformations → collapse
  - Structure should be replaced
  - Significant interruption of Airport activities

Structural resistance of tunnel in fire situation	PBD results		
	Fire resistance [minutes]	Maximum deformations [mm]	Residual deformations [mm]
ISO fire	36	Collapse	
RWS fire	27	Collapse	

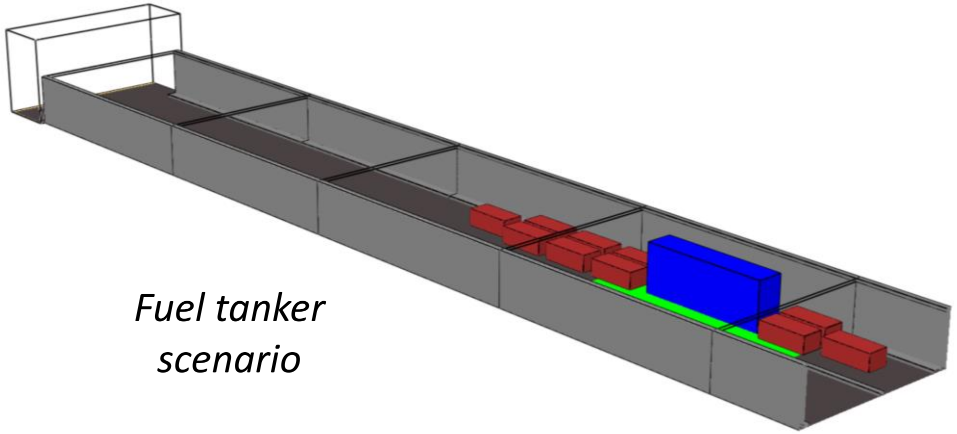
PBD approach – Natural fire scenarios

CFD calculations with FDS

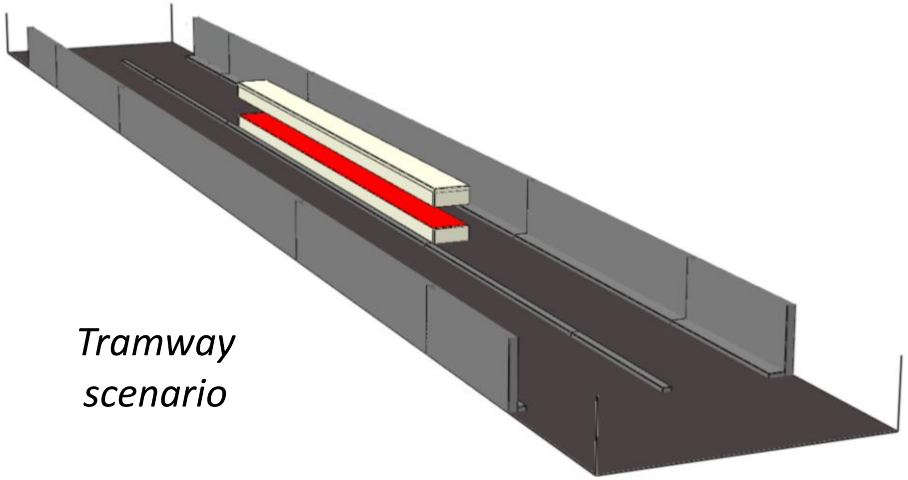
- Geometry of the tunnel
- Reaction of combustion
- Natural ventilation

HRR curves according to CETU guide

- Fuel tanker **200 MW**
- HGV **100 MW**
- Tramway **~64 MW** (publications)



Fuel tanker scenario

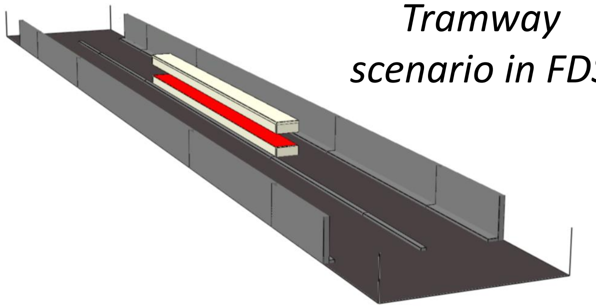


Tramway scenario

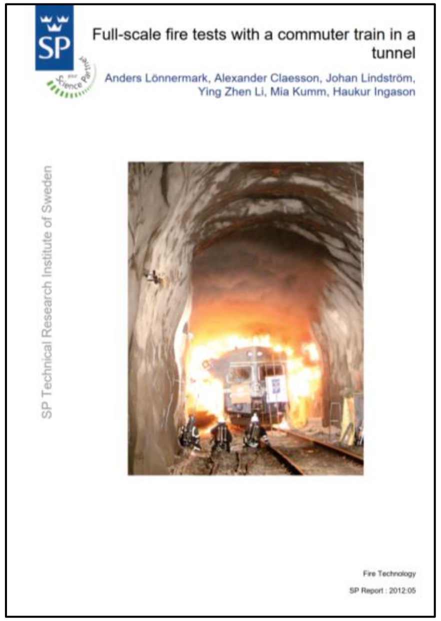
PBD approach – Natural fire scenarios

Tramway 64 MW

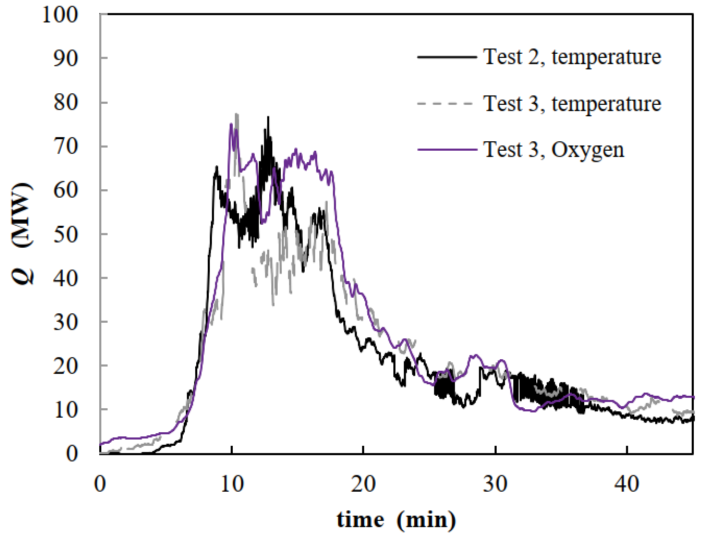
- HRR curve according to publications and experiments for train fires



Tramway scenario in FDS



Publication as reference



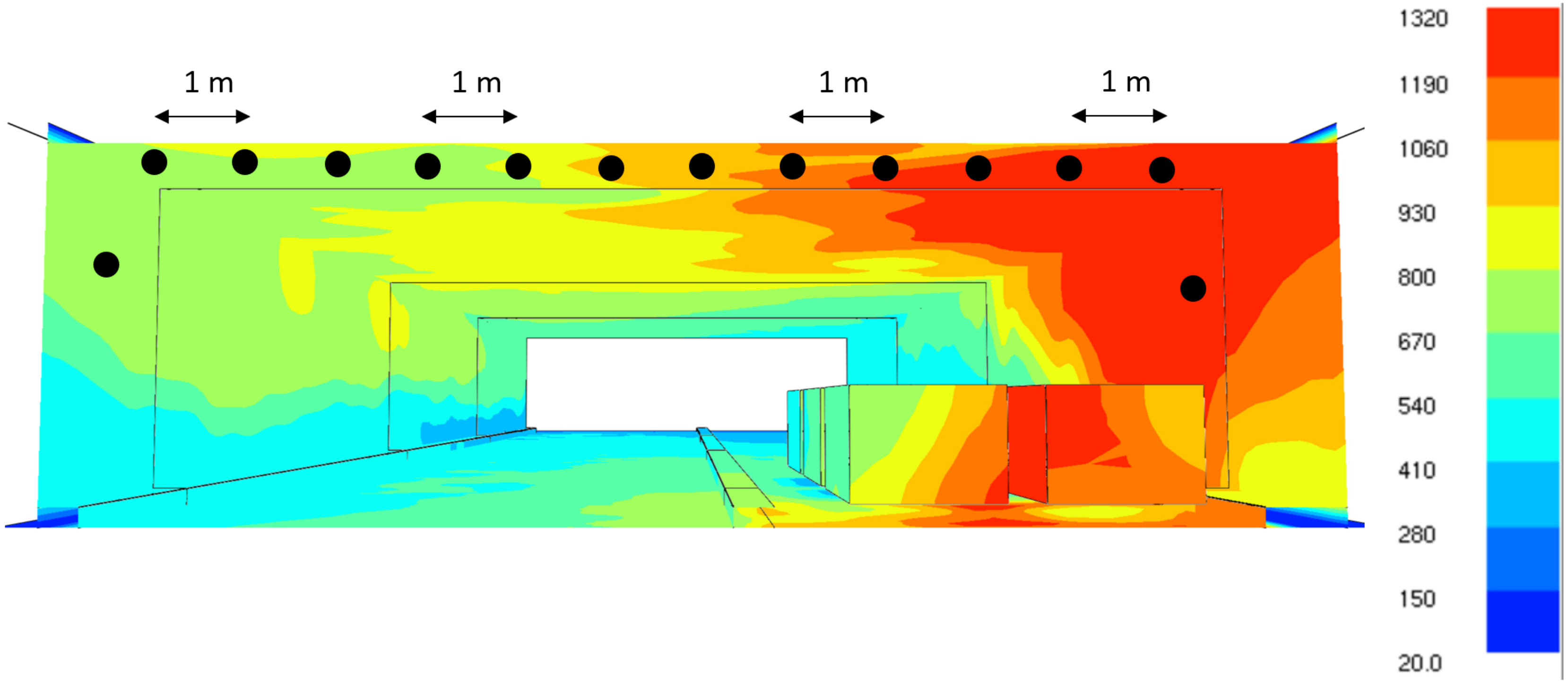
HRR tests in experiments

Additional fire load density considered

PBD approach – Natural fire scenarios

CFD calculations with FDS

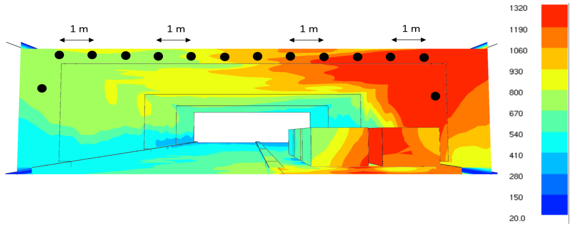
- AST devices on ceiling and walls

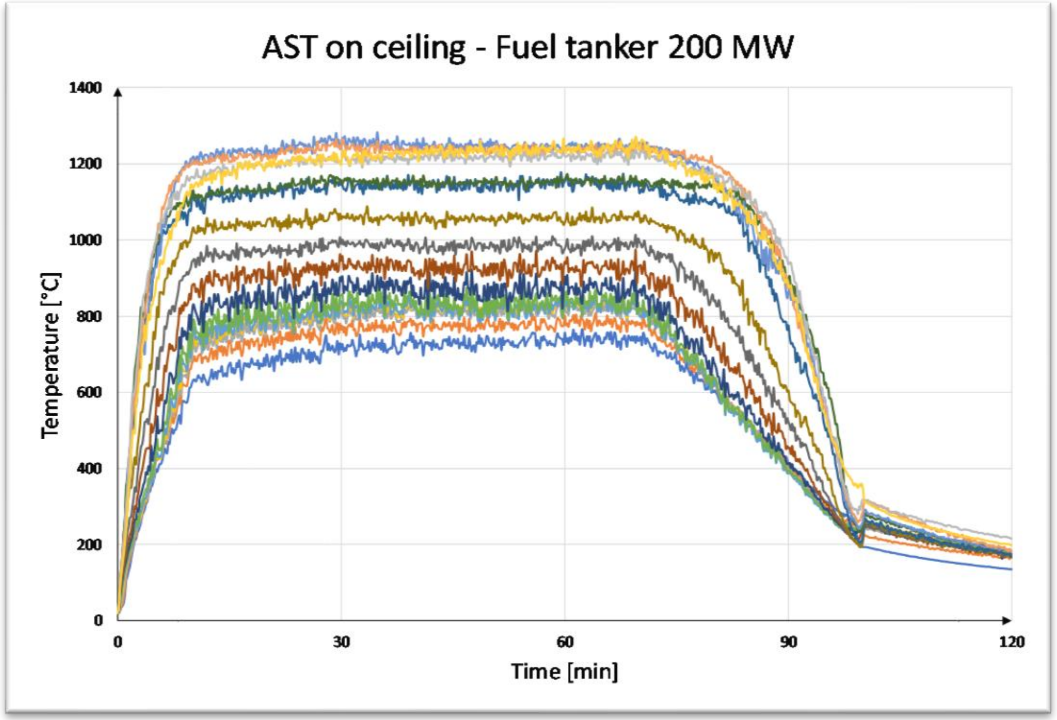


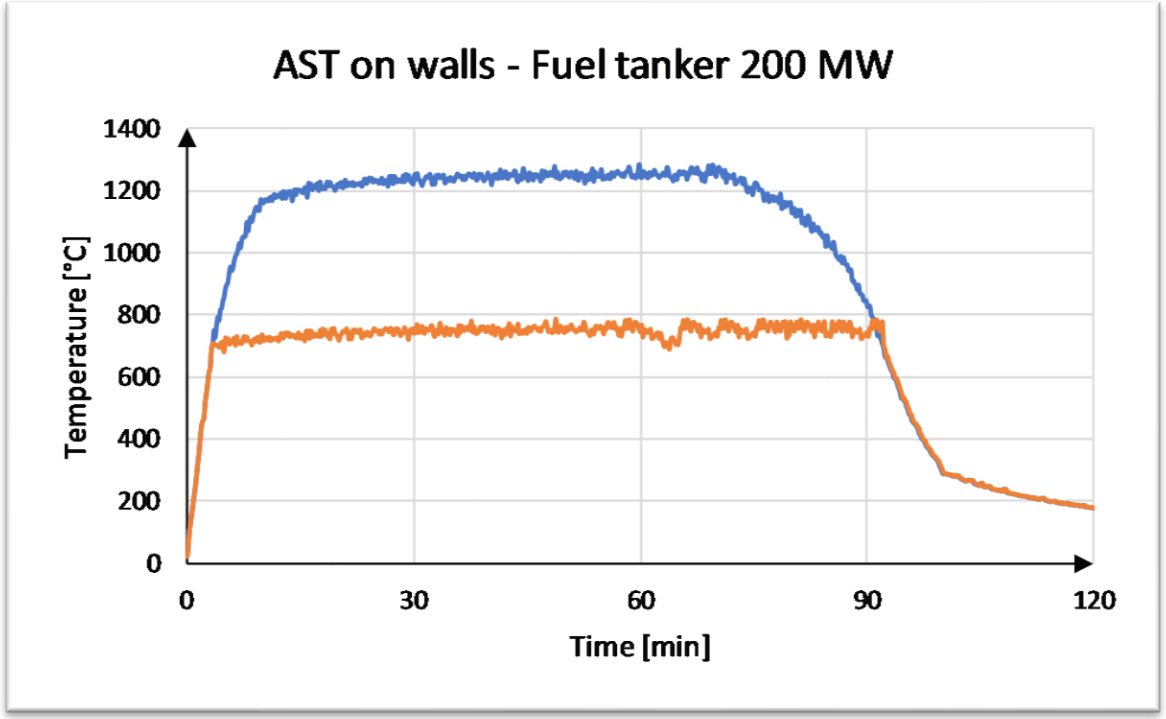
PBD approach – Natural fire scenarios

CFD calculations with FDS

- AST devices on ceiling and walls



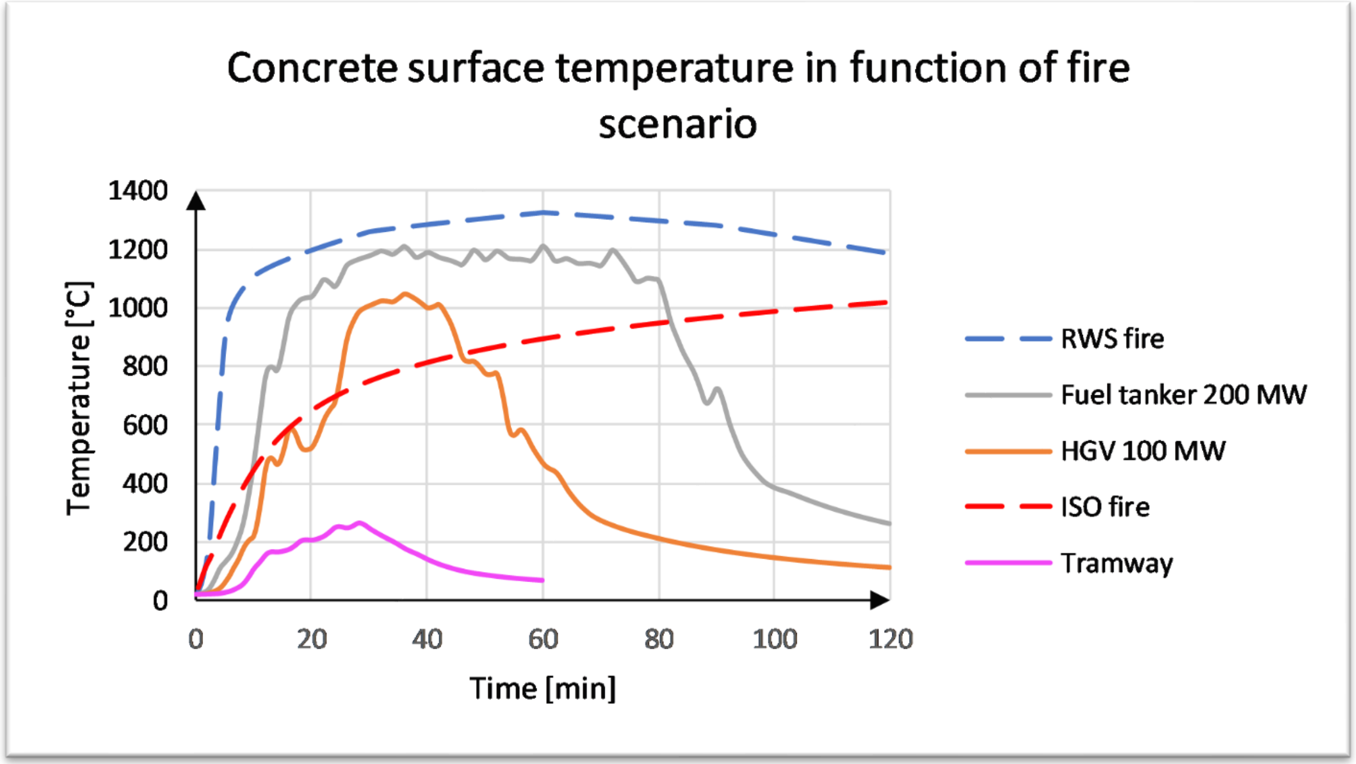


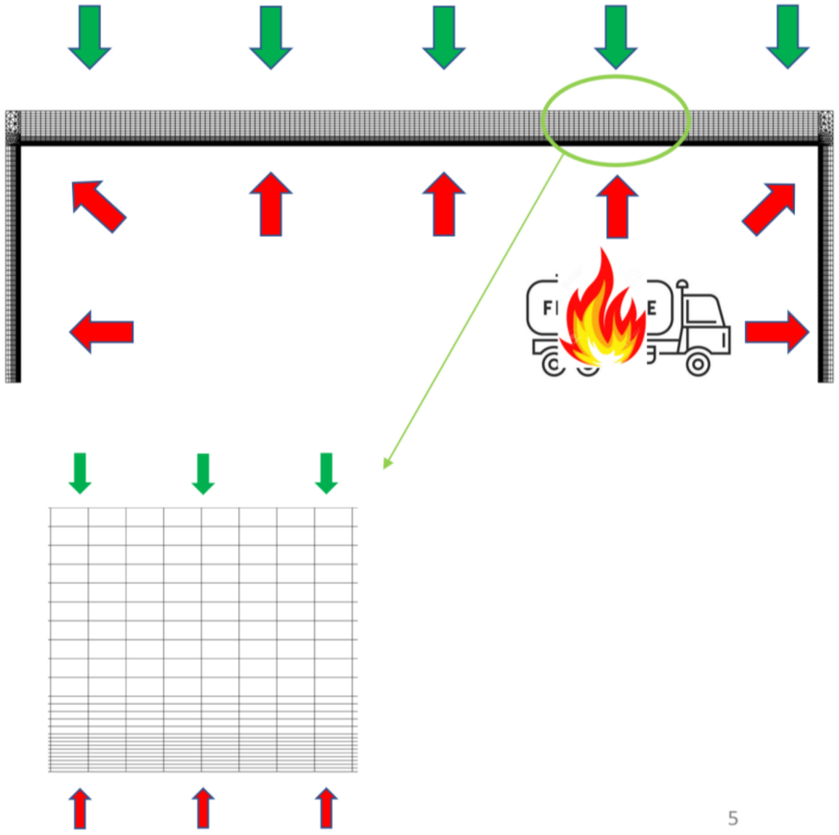


PBD approach – Natural fire scenarios

Thermal calculations

- Thermal stresses of CFD model as boundary conditions



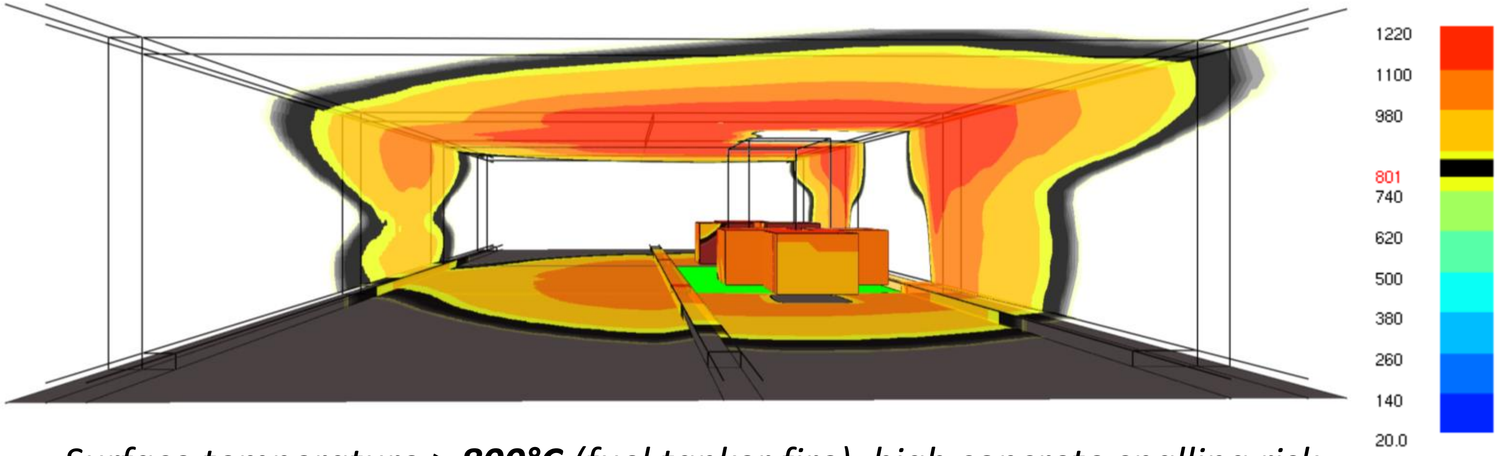


PBD approach – Natural fire scenarios

Structural calculations

- ISO / RWS / 100 MW / 200 MW: KO
- Tramway: OK
- No spalling considered
  - ~600 – 800°C

Structural resistance of tunnel in fire situation	PBD results		
	Fire resistance [minutes]	Maximum deformations [mm]	Residual deformations [mm]
ISO fire	36	Collapse	
RWS fire	27	Collapse	
Tramway	OK	25	13 - 15
HGV 100 MW	28	Collapse	
Fuel tanker 200 MW	27	Collapse	



*Surface temperature > **800°C** (fuel tanker fire): high concrete spalling risk*

Concrete spalling example

PBD approach – Natural fire scenarios

Solutions:

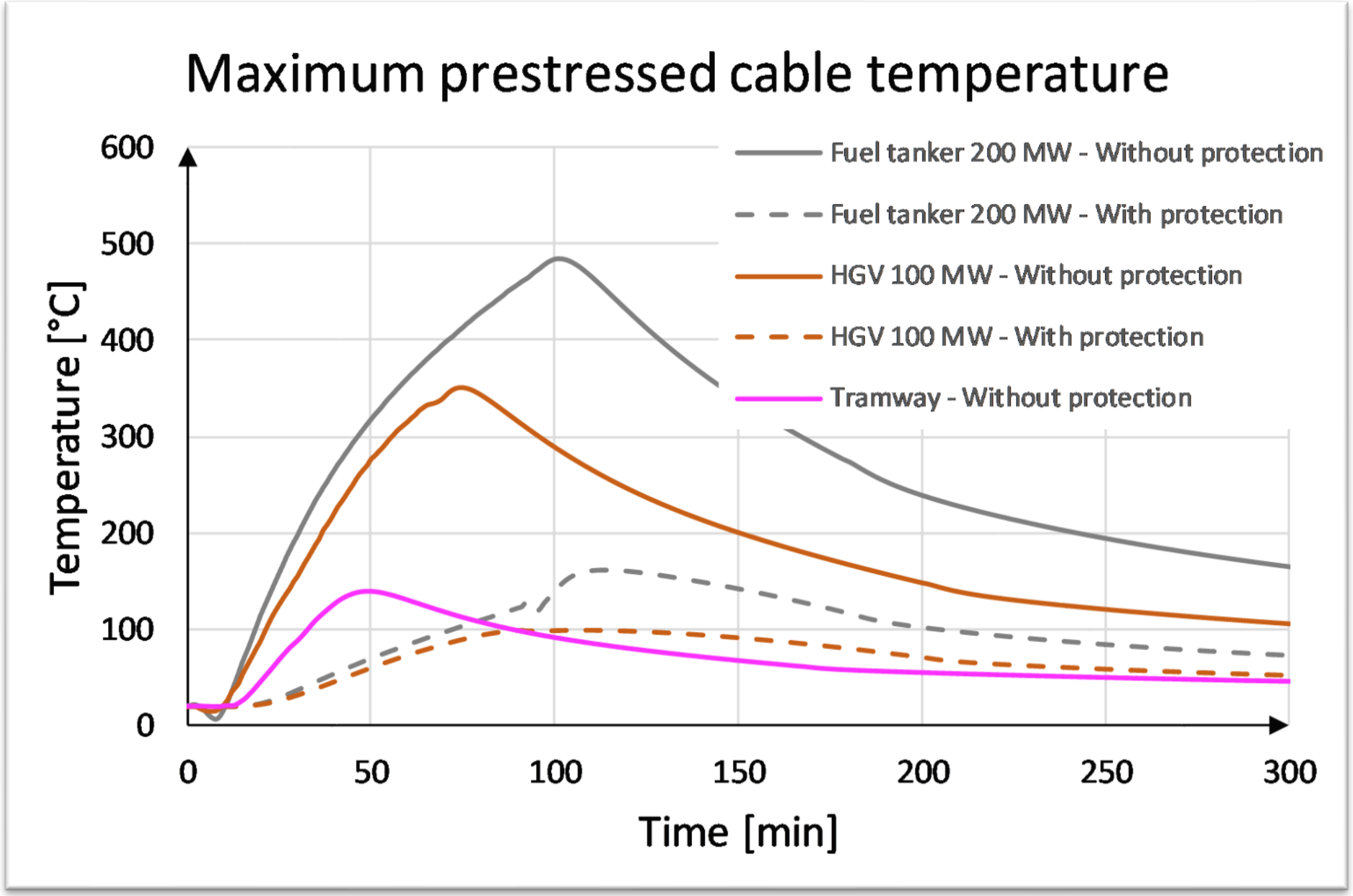
- **Organisational measures →** no HGV and non fuel tanker in this tunnel (*must take another itinerary*)
- **Passive measures →** Fire panels (*Promatect-H EI90 or similar*)
- **Active measures →** **Water mist installation**

Structural resistance of tunnel in fire situation	PBD results		
	Fire resistance [minutes]	Maximum deformations [mm]	Residual deformations [mm]
ISO fire	36	Collapse	
RWS fire	27	Collapse	
Tramway	OK	25	13 - 15
HGV 100 MW	28	Collapse	
Fuel tanker 200 MW	27	Collapse	

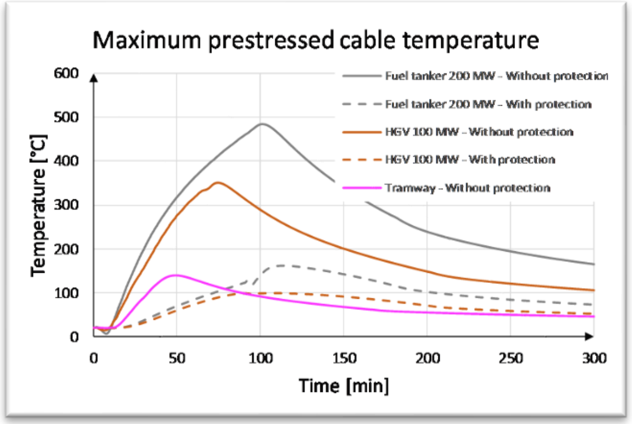
PBD approach – Solutions

Passive measures

- Walls and main part of the slab **need to be protected**

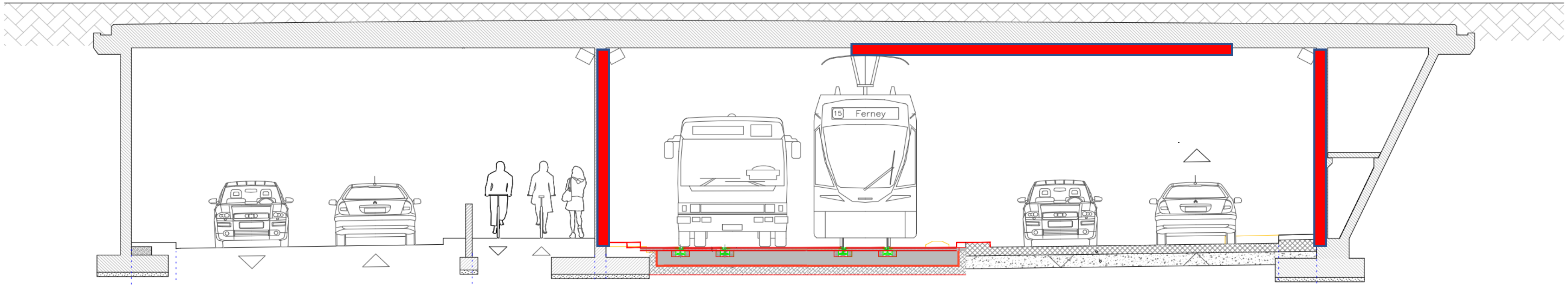


PBD approach – Solutions



Passive measures

- Walls and main part of the slab **need to be protected**

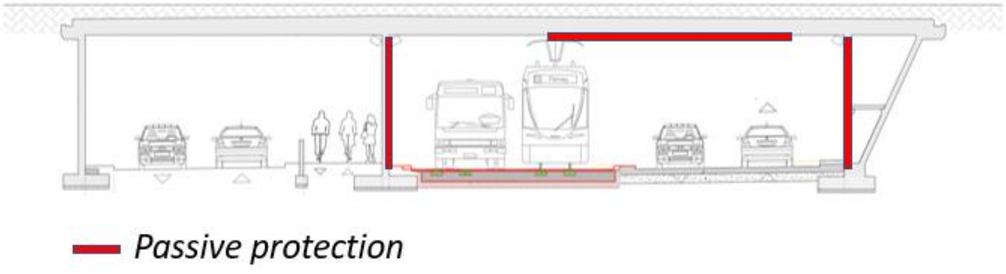


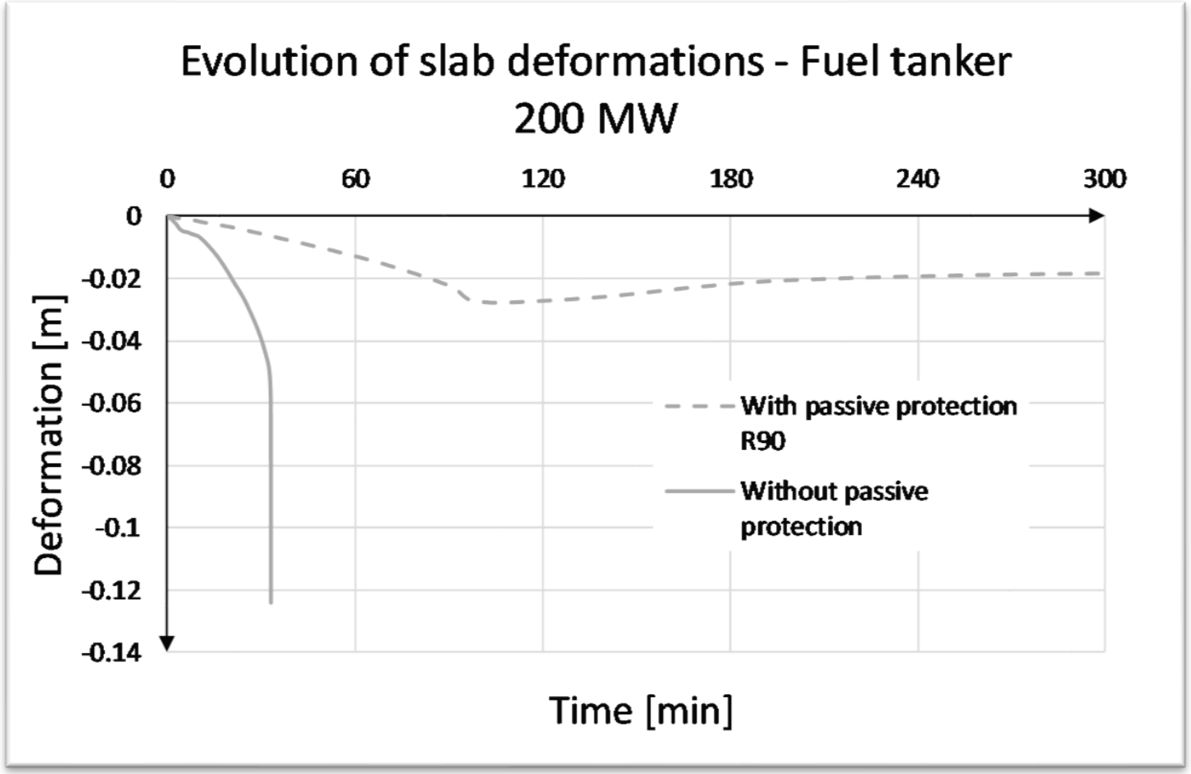
Passive protection

PBD approach – Solutions

Passive measures

- Walls and main part of the slab need to be protected



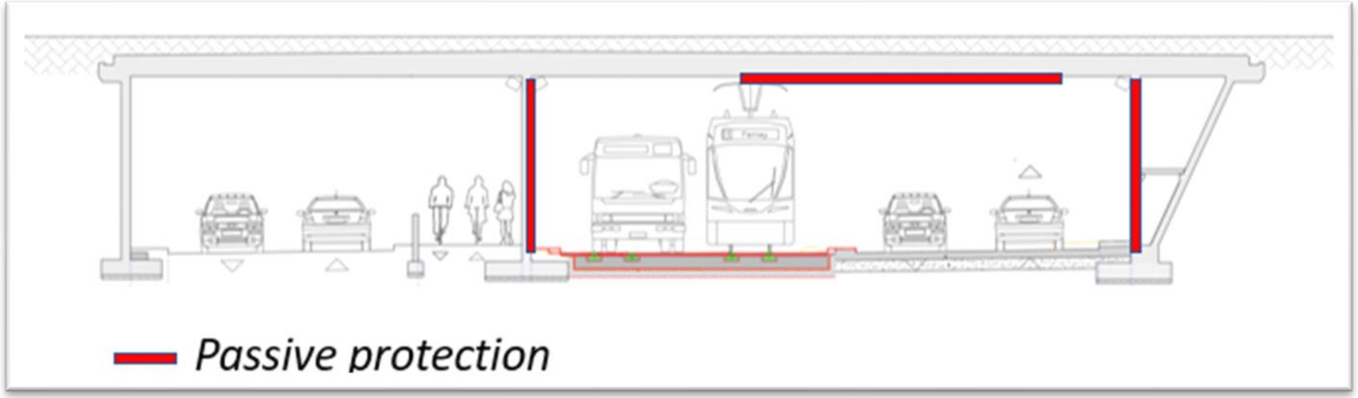


- Low deformations with **EI90 protection**
  - *Promatect-H **25 mm** or similar*

PBD approach – Solutions

Passive measures

- **Advantages:**
  - System reliability
  - Less maintenance
  - Very efficient
  - Good feedback

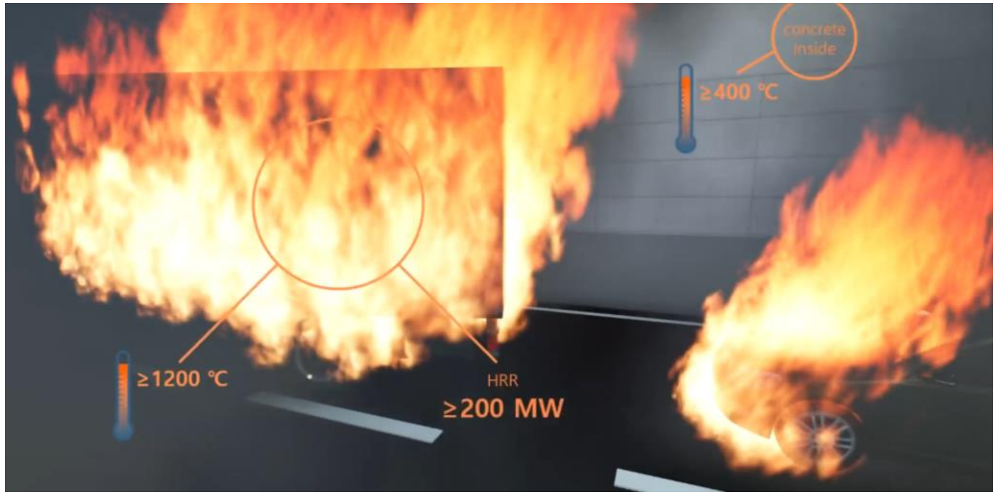


- **Drawbaks:**
  - **Very expensive solution ~450 € / m²**
  - (brand new) Technical installations to be replaced *post-fire*
  - Fire panels have to be replaced post-fire (need to close tunnel)
  - No (cooling) effect on fire

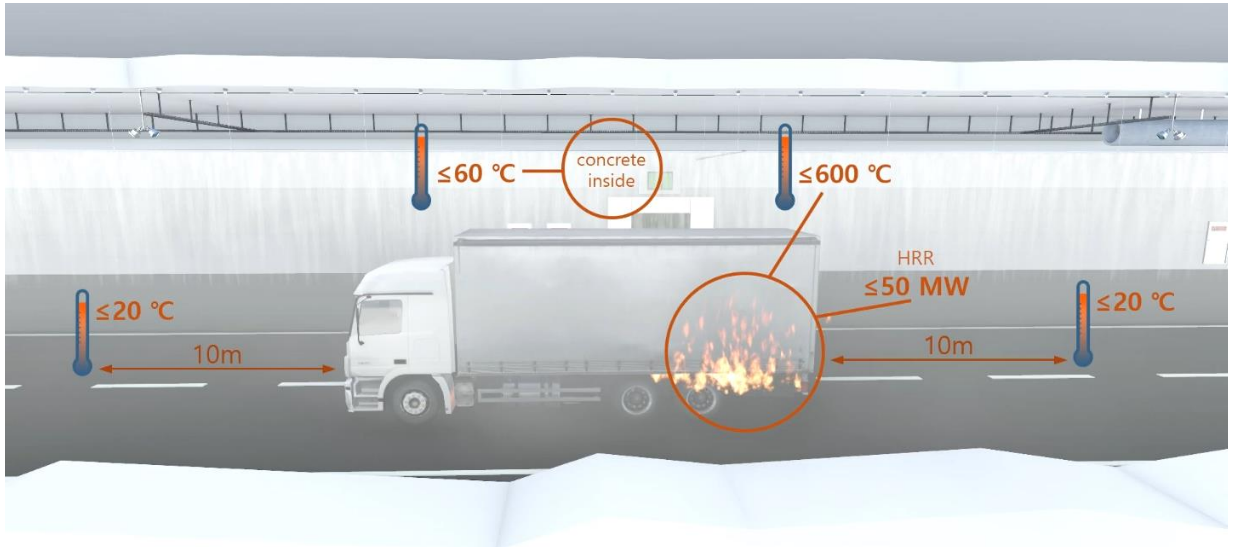
PBD approach – Solutions

Active measure: water mist solution

- Tested up to 250 MW fire



Without water mist system



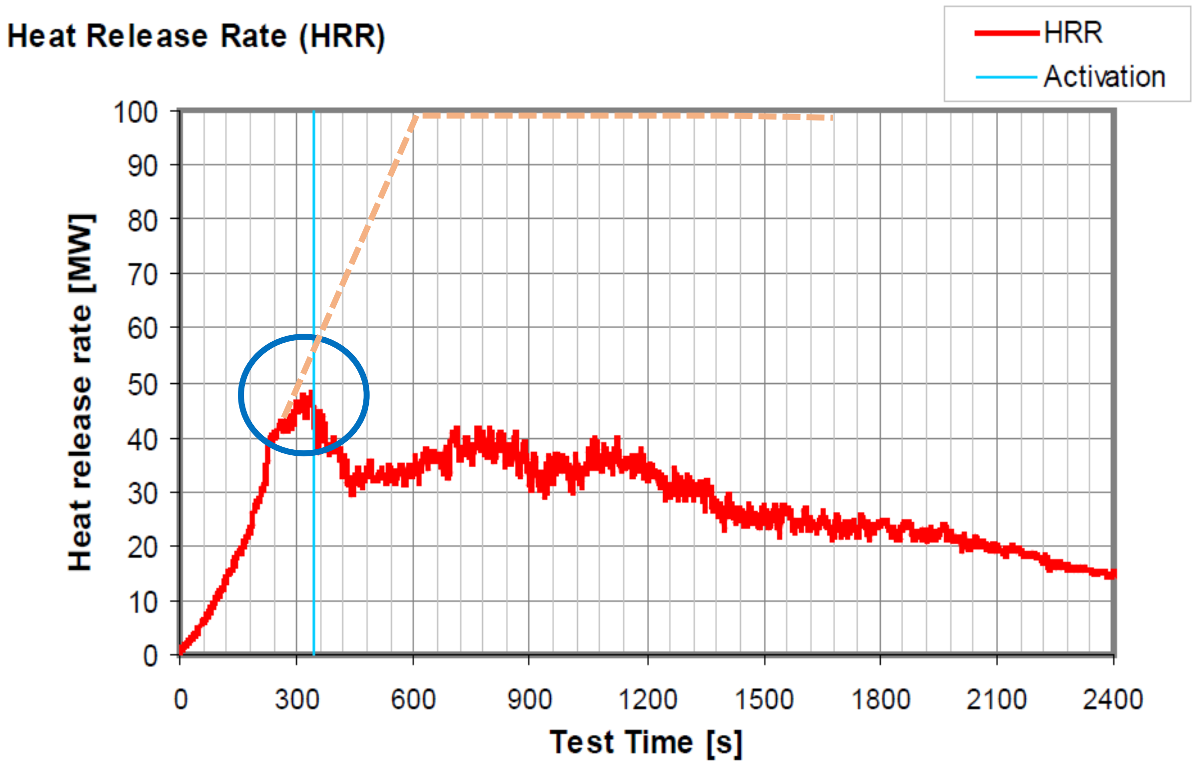
With water mist system

PBD approach – Solutions

Active measure: water mist solution

- Tested up to 250 MW fire

- **Cooling effect** on fire after activation
- Quick HRR mitigation at the activation time



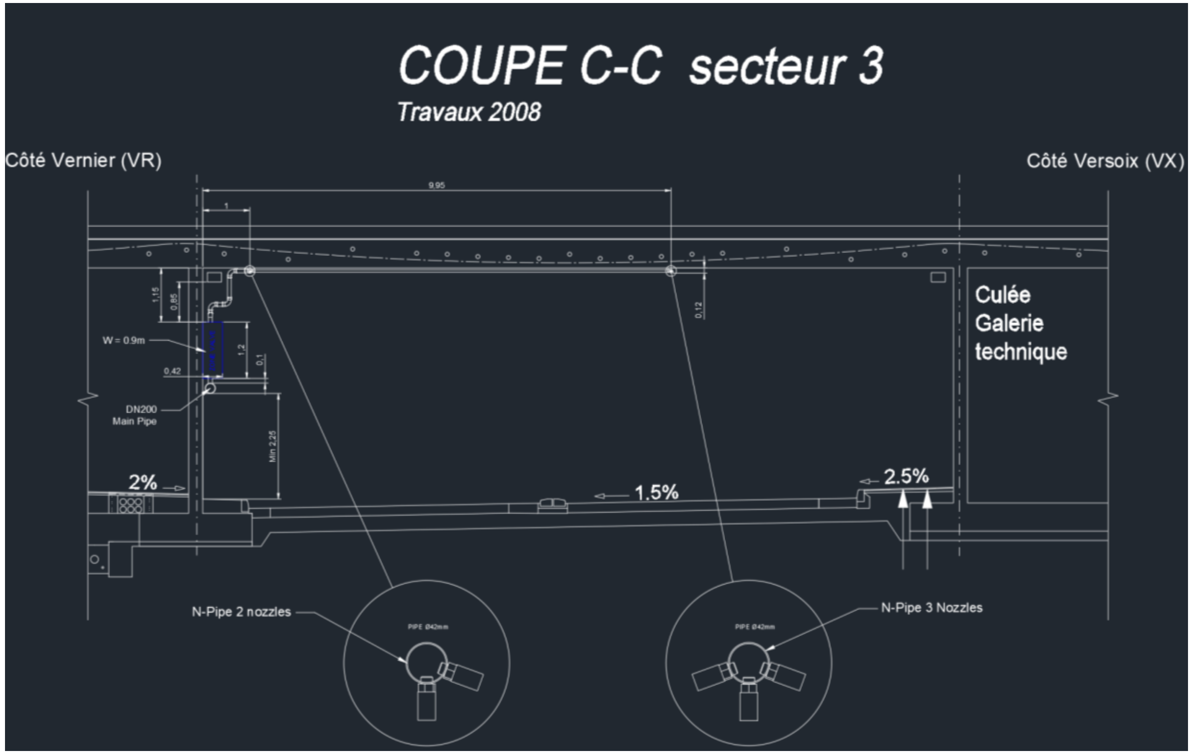
Test for HGV fire – 100 MW

PBD approach – Solutions

Active measure

- **Advantages:**
  - Limited fire development
  - Easier and safer for the firefighting
  - Low damage risk for tunnel structures and technical installations

- **Drawbaks:**
  - Reliability 90 < P < 98 %
  - Damages to nozzles (clogging, impacts)
  - Smoke destratification (evacuation)
  - Maintenance required



Results and conclusion

Current structural situation is unacceptable in case of fire

- Huge deformations of the slab → **collapse very likely to happen**
- Incompatibility with Airport activities (can’t be closed or interrupted for days)

Need to improve structural behavior and safety

- **Mixed solution:** localized passive protection + active measure

1. **Fire panels in the most sensitives parts of the structure**
2. **Full water mist system coupled to a smoke/thermal/camera detection**

PBD approach offers best solutions to clients in order to improve safety of structures and guaranty the airport operations

Thanks for you attention

Questions are welcome ☺

Eric Tonicello – ISI Sàrl – Lausanne, Switzerland – eric.tonicello@incendie.ch

Julien Duboc – ISI Sàrl – Lausanne, Switzerland – julien.duboc@incendie.ch