CFD and Evacuation simulations for three railway tunnels. Challenges in case of natural ventilation

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Introduction

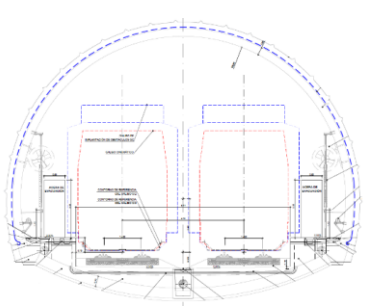
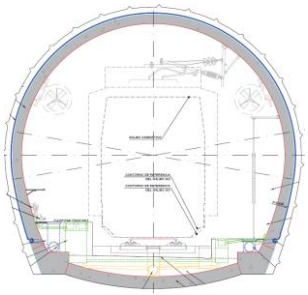
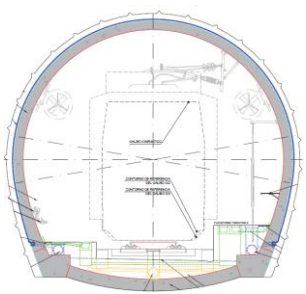
Fire test in the Brunsberg tunnel

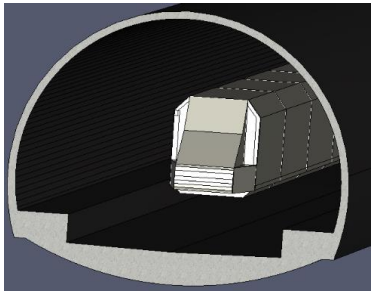
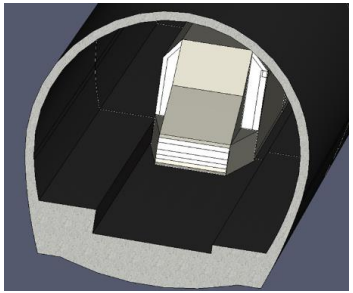
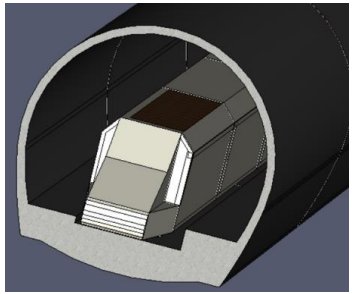
Fire events in railway tunnels can be catastrophic for different reasons:

- Potential high HRR (depending on the train)
- High number of passengers to evacuate
- Some railway tunnels are considerably old and do not have mechanical ventilation
- Reduced space for the smoke compared to other type of tunnels

IMPORTANCE OF KNOWLEDGE ABOUT RISKS AND MITIGATION MEASURES

MAIN CHARACTERISTICS OF THE TUNNELS

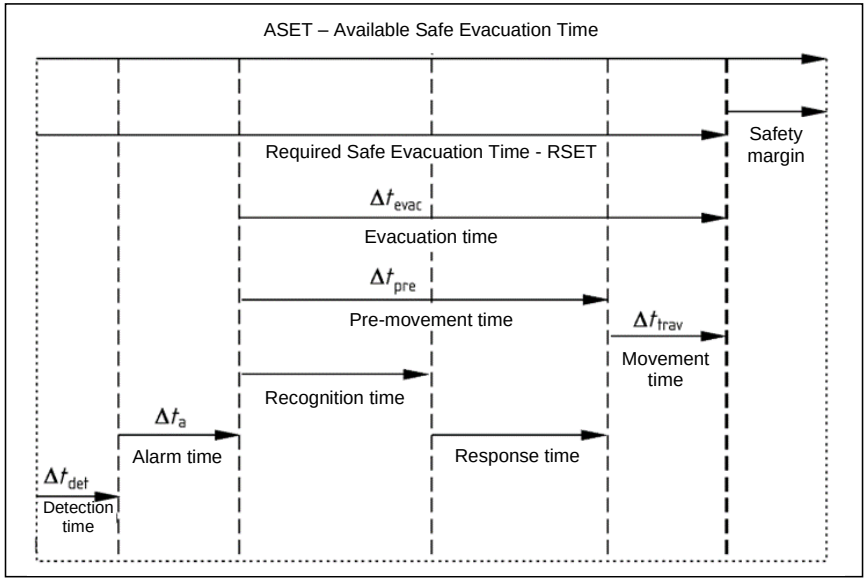




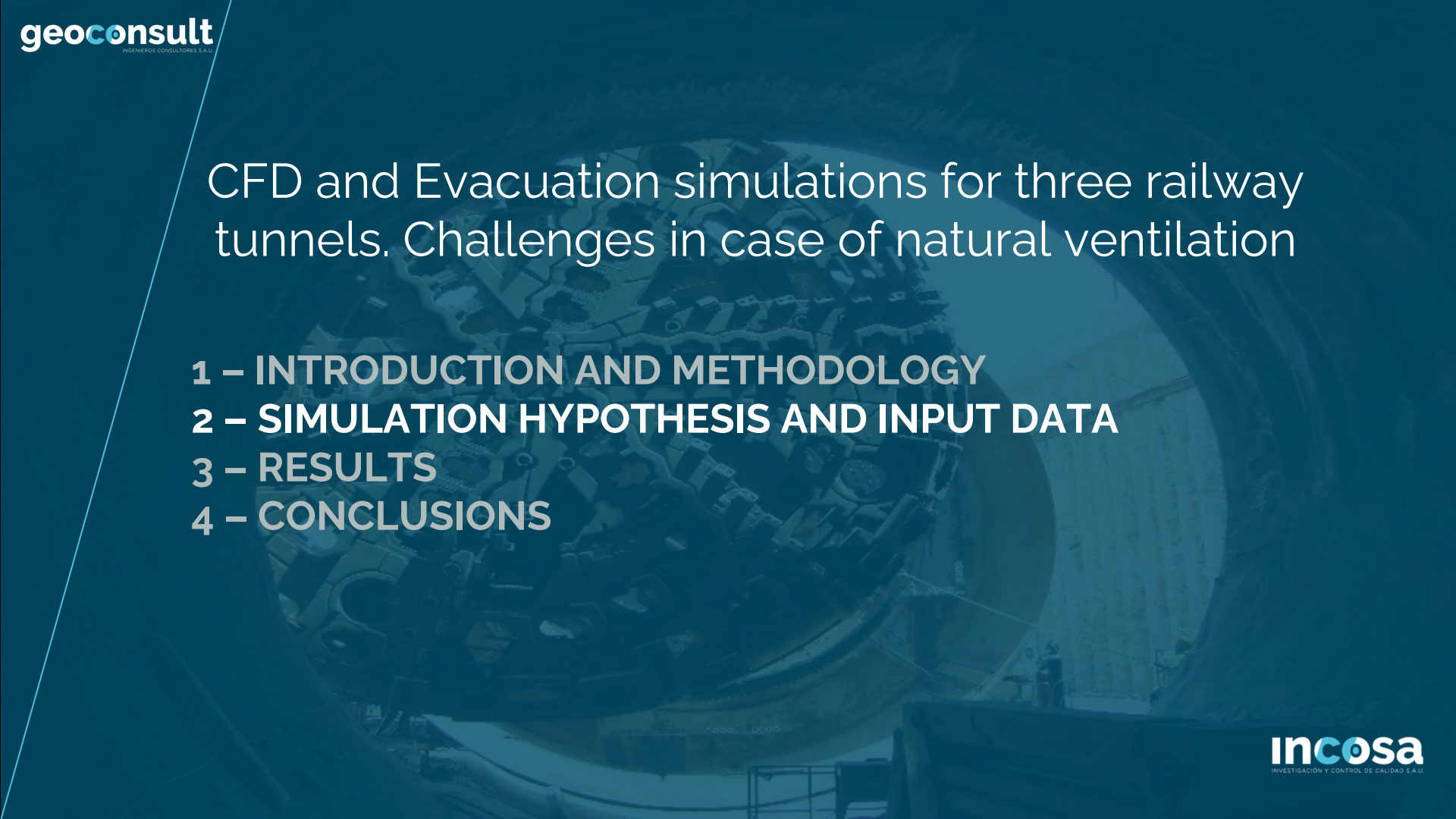




	Scenario 1	Scenario 2	Scenario 3
Cross section	89 m^2	53 m^2	53 m^2
Evacuation walkway width	1.26 m	1.60 m	1.73 m
Slope	-1.7%	-1.8%	1.8%

ASET vs **RSET**

CFD fire simulations with Pyrosim - FDS ⟷ Evacuation simulations with Pathfinder





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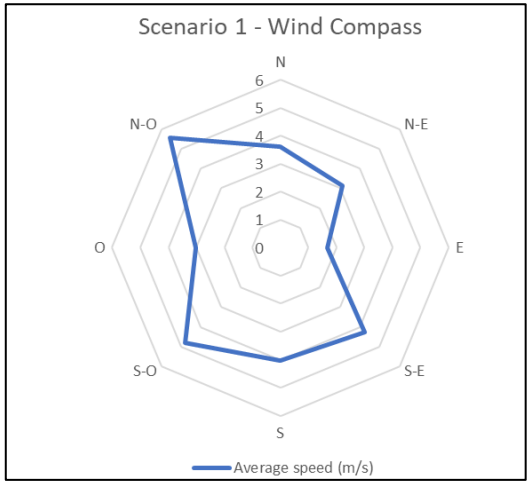
1 – INTRODUCTION AND METHODOLOGY
2 – SIMULATION HYPOTHESIS AND INPUT DATA
3 – RESULTS
4 – CONCLUSIONS

Simulation Hypothesis and Input Data

- Geometry
- Fire characteristics
- Boundary conditions
- Evacuation parameters

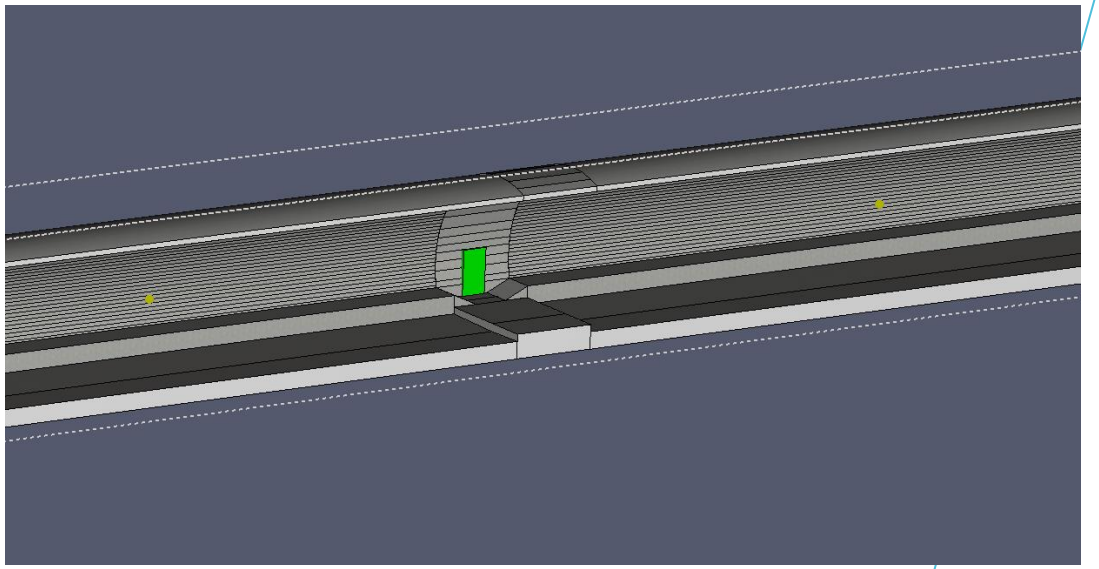


Simulation Hypothesis and Input Data

Geometry

Main parameters:

- Cross section of the tunnel
- Height of the tunnel
- Slope
- Distance to Emergency exits



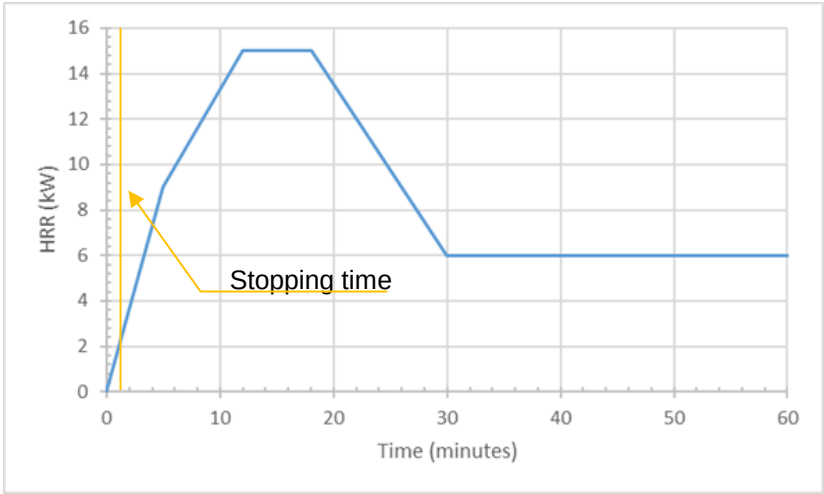
Illustrative view of the model of the scenario 1

Simulation Hypothesis and Input Data

Fire characteristics

Main parameters:

- HRR considered
- Combustion properties
- Beginning time of the scenario



HRR curve according to Spanish standard IFI

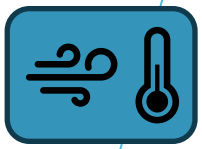
Combustion Property	Value
Chemical formula	$C_{5.77}\ H_{6.25}\ O_{1.63}$
Energy per kg O_2 consumed	11.900 kJ/kg
Soot yield	0.0602 g/g
CO yield	0.0705 g/g

Polyester properties according to SFPE Handbook

Type of traffic	Maximum HRR	Fire duration
Only passengers' trains	15 MW	1 h
Passengers and Freight trains	30 MW	2 h
Dangerous goods trains	100 MW	2 h

HRR per train type according to Spanish standard IFI

Simulation Hypothesis and Input Data



Boundary conditions

Main parameters:

- Walls temperature
- Outdoor temperature
- Pressure difference (wind)

Tunnel	Wall temperature	Air temperature
Tunnel 1	6.00 ºC	-1.68 ºC
Tunnel 2	5.95 ºC	-1.41 ºC
Tunnel 3	5.95 ºC	-1.41 ºC

Temperatures according to local weather stations for the month of January

Tunnel	Height difference portals [m]	Temp. Difference portals [ºC]	Maximum wind (P95) [m/s]	Total Pressure difference [Pa]
Tunnel 1	41,732	11,72	3,03	24,78
Tunnel 2	-113,79	8,79	3,11	48,96
Tunnel 3	112,55	8,79	3,11	48,49

External wind and pressure difference between tunnel portals

Simulation Hypothesis and Input Data

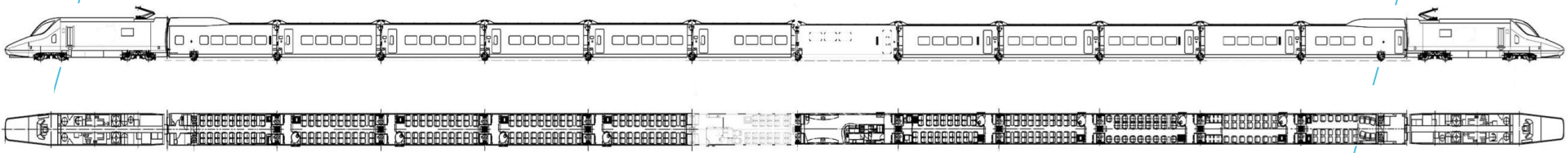
Evacuation parameters

Main parameters:

- Total number of people
- Movement speed
- Population distribution

Type of passengers	Relative weight (%)	Horizontal speed (m/s)		Speed on stairs (m/s)	
		Avg.	Range (uniform)	Avg.	Range (uniform)
Female < 30 yrs.	12%	1.24	0.93-1.55	0.75	0,56-0,94
Female 30-50 yrs.	12%	0.95	0.71-1.19	0.65	0,49-0,81
Female > 50 yrs.	16%	0.75	0.56-0.94	0.6	0,45-0,75
Female PRM 1	10%	0.57	0.43-0.71	0.45	0,34-0,56
Male < 30 yrs.	12%	1.48	1.11-1.85	0.86	0,76-1,26
Male 30-50 yrs.	12%	1.3	0.97-1.62	0.86	0,64-1,07
Male > 50 yrs.	16%	1.12	0.84-1.4	0.67	0,50-0,84
Male PRM 1	10%	0.85	0.64-1.06	0.51	0,38-0,64
PMR 2	-	0.69	0.13-1.29	-	

Population groups and walking speeds considered



Train considered for the simulations (capacity: 730 p → 2 x 365 p)

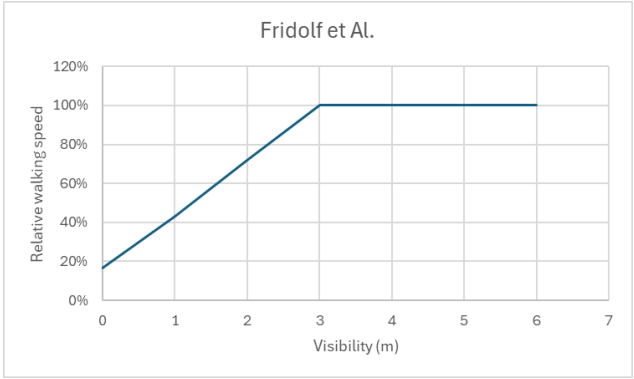
Simulation Hypothesis and Input Data

Evacuation parameters

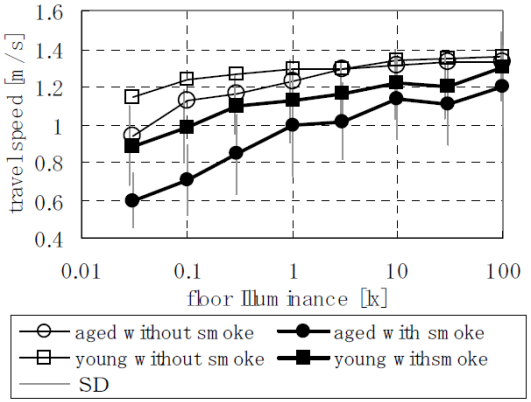
Additional considerations

- Step to exit the train
- Speed reduction due to smoke
- Start of the evacuation (pre-movement times)

Step to get out of the train



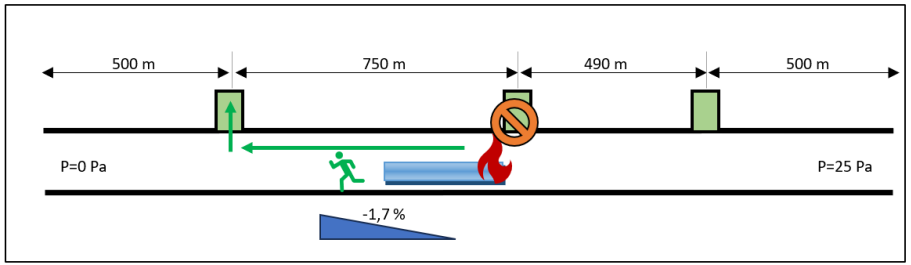
Speed reduction due to smoke (Fridolf et Al.)



Speed reduction due to smoke and lighting level (Yuki Akikuzi et Al.)

Overview of the scenarios

SCENARIO 1



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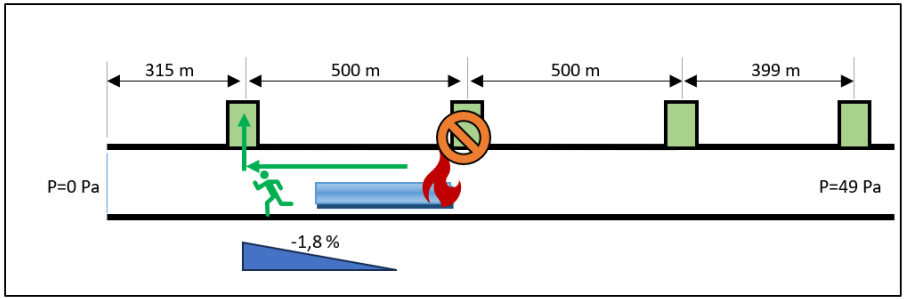

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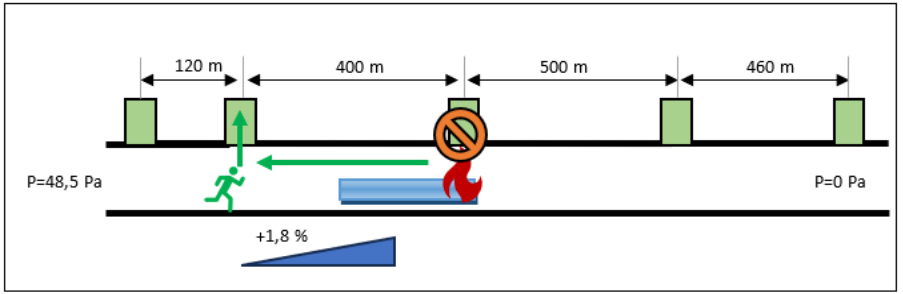

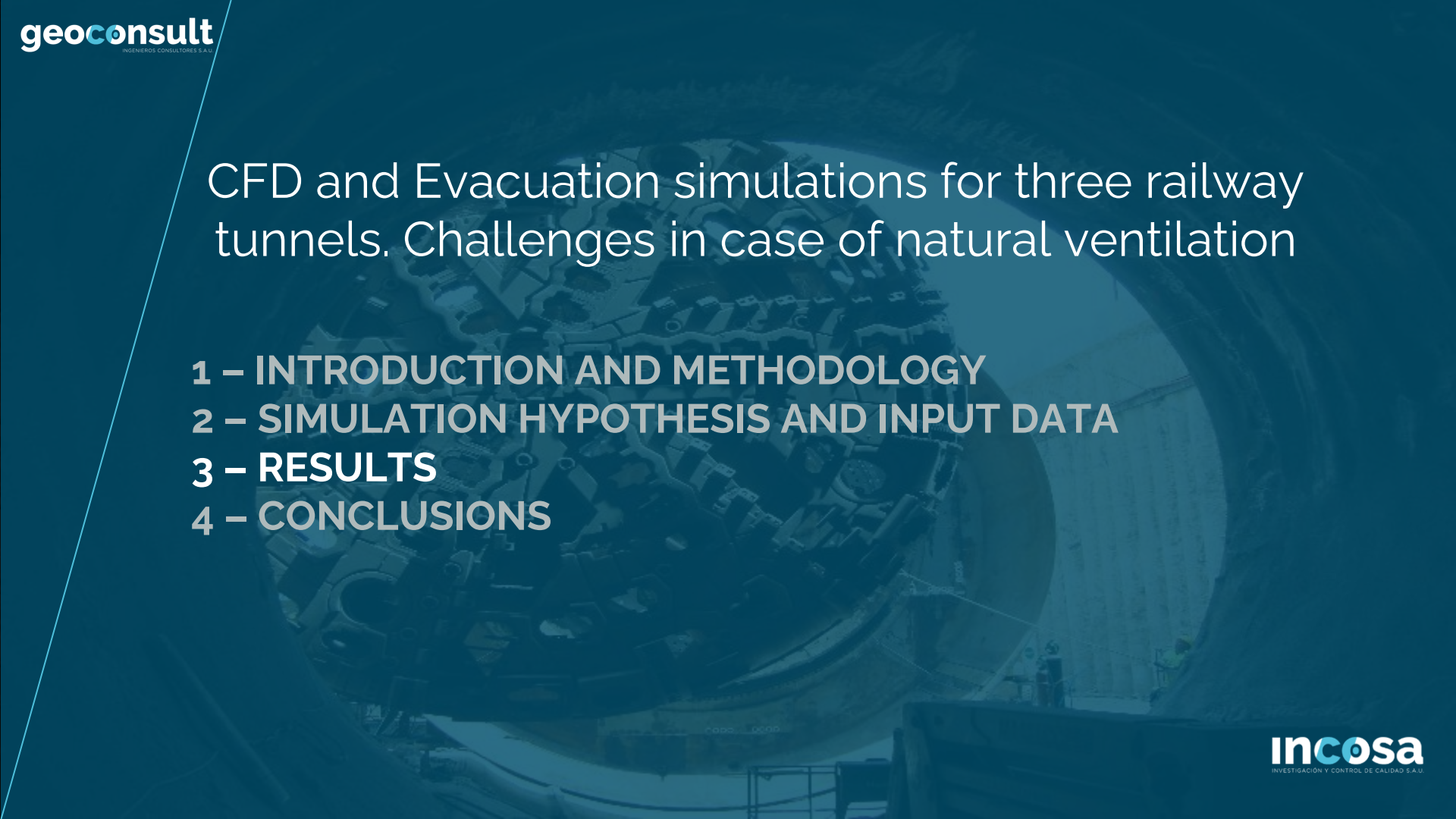

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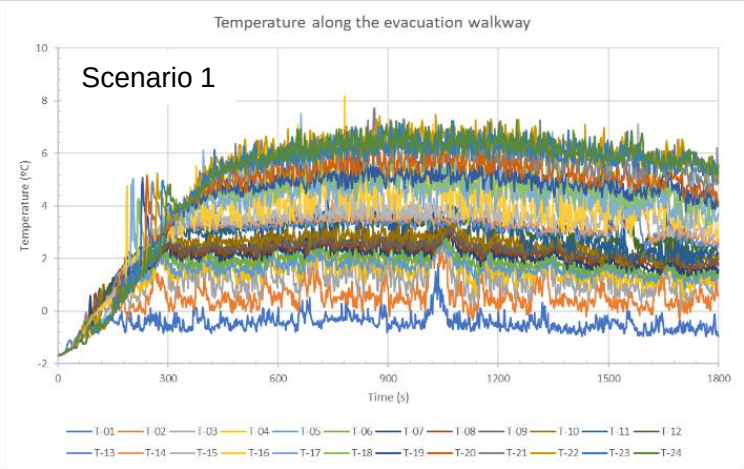
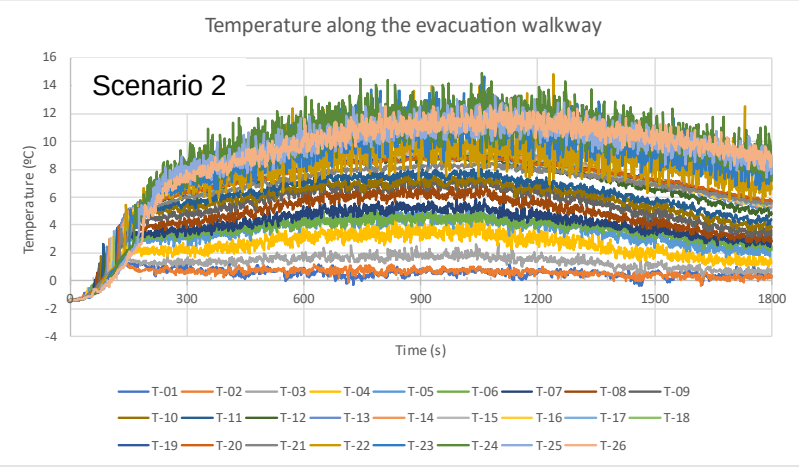
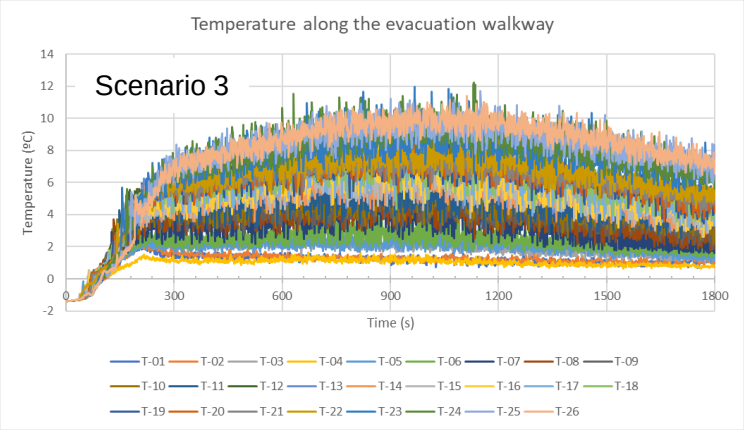
Temperature

Results

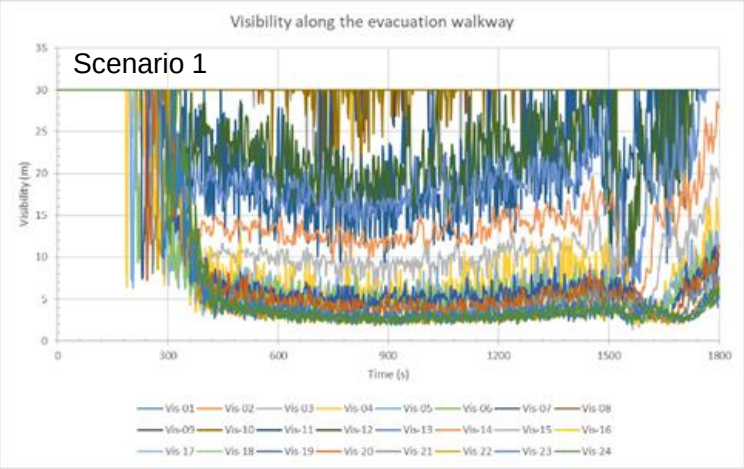


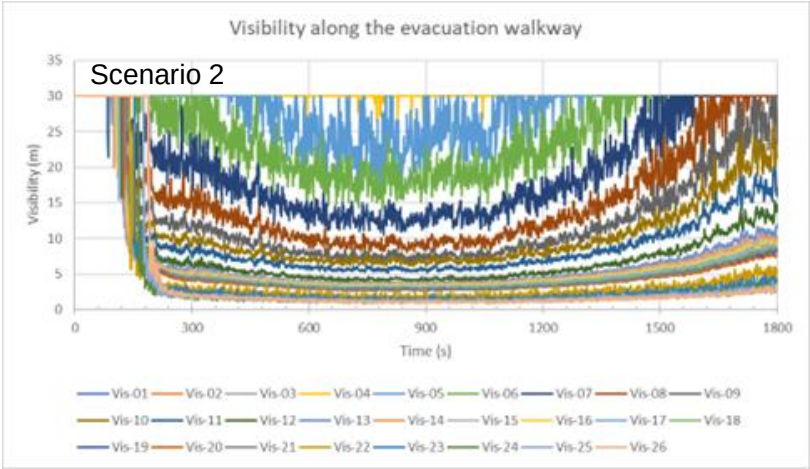


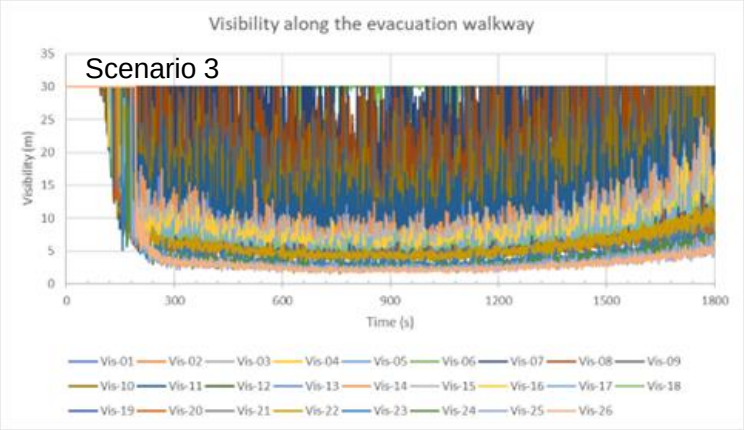


	ΔTemp
Scenario 1	10ºC
Scenario 2	17ºC
Scenario 3	13ºC

Visibility



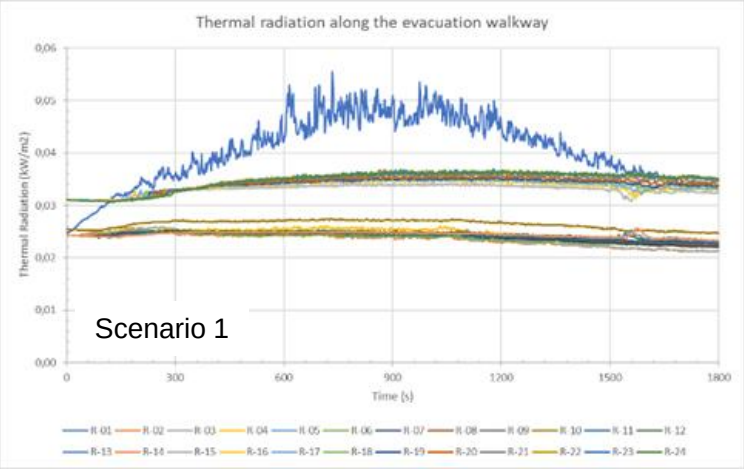


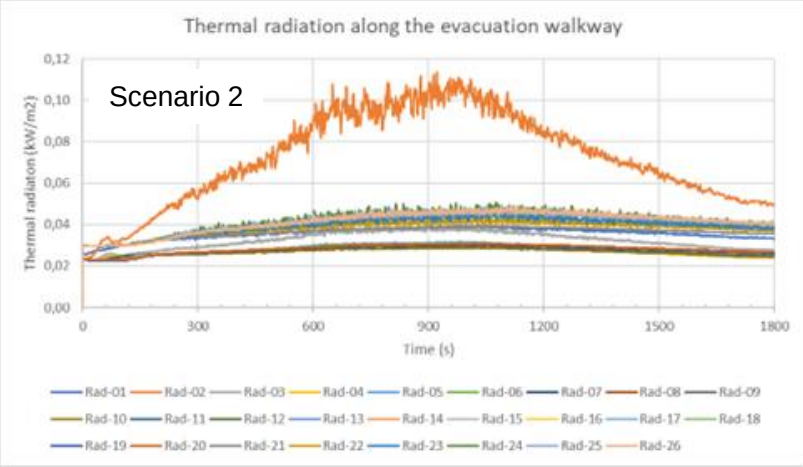


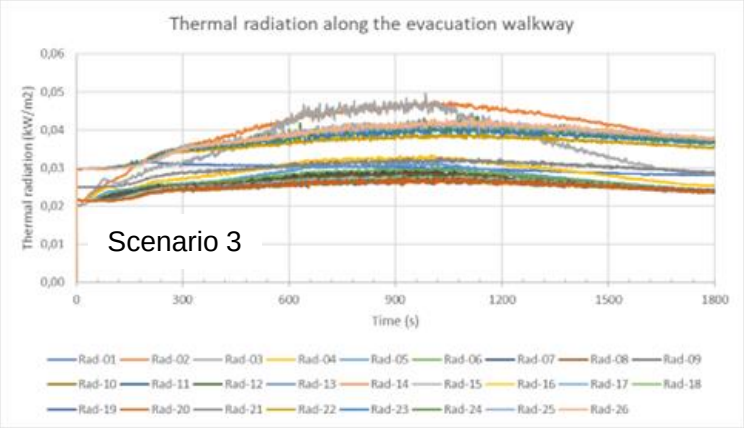
	Visibility
Scenario 1	≈ 3 m
Scenario 2	≈ 1.5 m
Scenario 3	≈ 2.5 m

Thermal Radiation

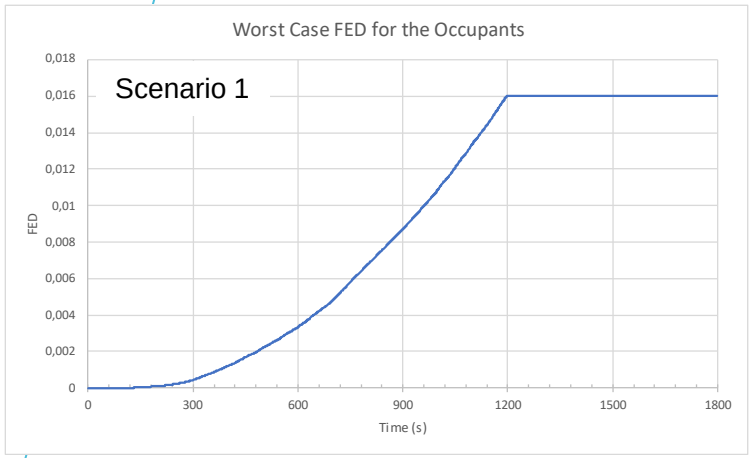
Results

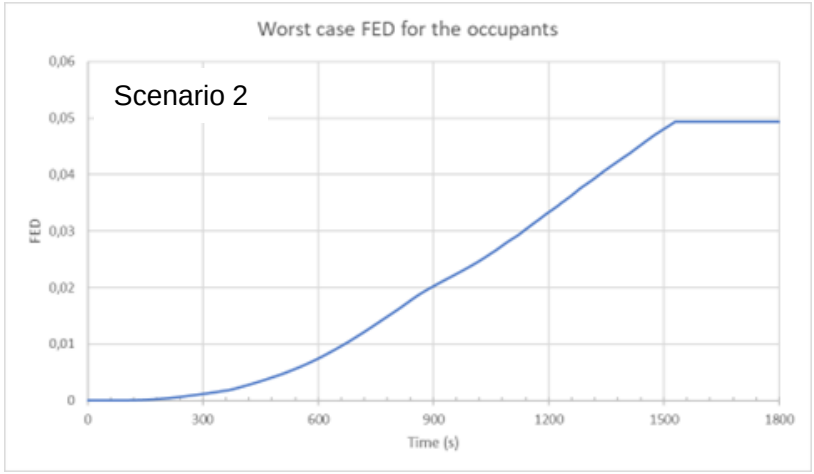


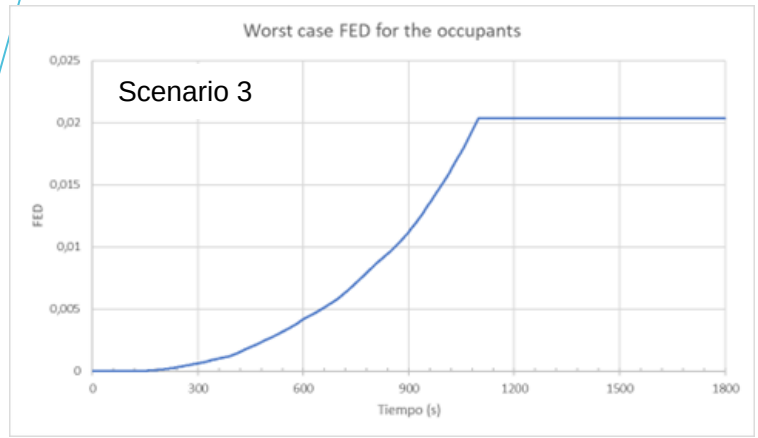




	Radiation
Scenario 1	< 60 W/m^2
Scenario 2	≈ 110 W/m^2
Scenario 3	< 50 W/m^2







	FED
Scenario 1	0.016
Scenario 2	0.050
Scenario 3	0.020

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Overview

1	Absence of mechanical ventilation	Important reduction on visibility at the evacuation walkways
2	Temperature, radiation and FED	Less relevant than Visibility. Even more considering the improvements on the onboard materials due to latest standards
3	Tunnel Geometry	Highly relevant parameter. Tunnel size and slope can be comparable in relevance with the fire definition.

Conclusions

1. For tunnels with old trains in service, mechanical ventilation necessity has to be analyzed, as it may prevent serious consequences in case of fire

2. If mechanical ventilation is not possible → Mitigation measures should be considered:

- Low height emergency lighting
- Handrails
- Backlit evacuation signs
- Light beacons at evacuation path

Thank you for your attention

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