Numerical simulations for road tunnels fire safety

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Motivations and Targets

Ruins of the Mont-Blanc tunnel fire (1999)
Fire duration: 53h; Fatalities: 39
(including a firefighters and a security guard).

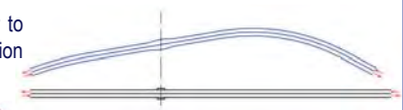
Among the different sections of a road infrastructure, accidents occurred into road tunnels are actually the most effective in terms of victims and damages. European government is facing this dramatic issue through the introduction of Fire Safety Engineering methods and performance based approach in the tunnel safety regulation.

The target of the Condó road tunnel analysis is the evaluation of the smoke propagation during a tunnel fire and its effect on the success of the evacuation, in particular the following aspects will be presented:

- Prediction of the **smoke propagation** during a tunnel fire;
- Comparison between the **mechanical and the human detection times**;
- Comparison between the **prescriptive based and performance based approaches.**

Modelling

The curved shape was linearized in order to **optimize** the smoke propagation calculation in relation to the mesh refinement.

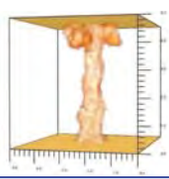


The real cross section is closely replicated into the Condó road tunnel digital model.

Fire behaviour
- Mass burning rate, $\dot{m}$
- Temperature, T
- Height of flame, H_f
- Fire duration, t
- Released energy, E

Boundary conditions
- Burning load
- Ventilation
- Enclosure

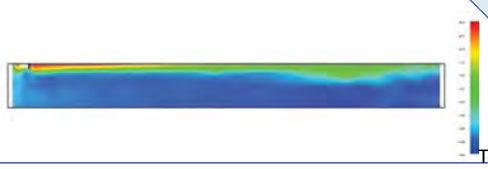
The design fire was a vehicle fire, which was defined through the coupling of the experimental data and theoretical relation.



GEOMETRY · FIRE · HVAC · EVACUATION

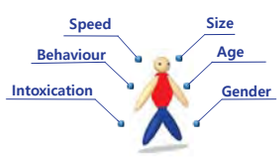
The mechanical ventilation is activated by the smoke detector distributed along the tunnel.
The number and the **real location** were replied into this model.

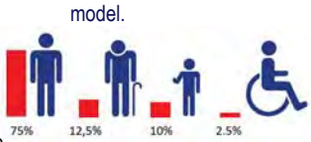
Fan size was defined through a sensitive analysis, in order to obtain the correct air flow.



Testo

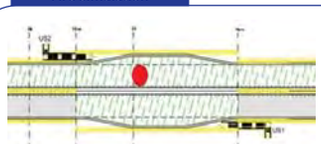
The evacuation process is deeply affected by the **human reaction** to fire.
Thus, the physical characteristics and typical behaviours are included in the human digital model.





The physical characteristics distribution was inspired by the same statistic investigation used in the TRANSFEU project.

Fire Simulation

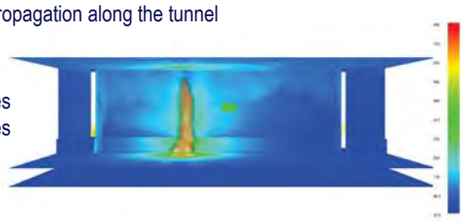


Fire location (next to the emergency exit)

The **fire simulation** was set considering a vehicle fire next to the emergency exit, in order to evaluate the **tenability conditions** along the escape path.

Among the many results of the fire simulation two were the most important:
- The Adiabatic Surface Temperature (AST)
- The smoke propagation along the tunnel

The **AST** reaches high temperatures (over 800°C)

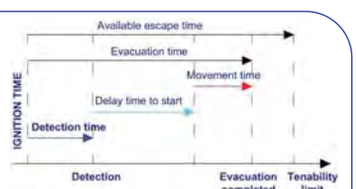


INPUT · INPUT · RESULTS · RESULTS

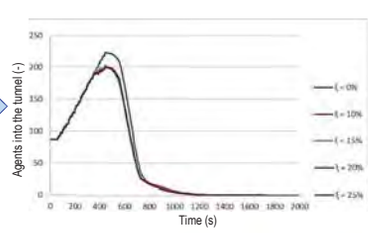
The nearest smoke detector is able to detect the fire **more then 6 minutes** after the fire ignition.

Evacuation Simulation

The **evacuation simulations** were set considering the mechanical detection time and the delay time to start, obtained from fire simulation and experimental data, respectively.

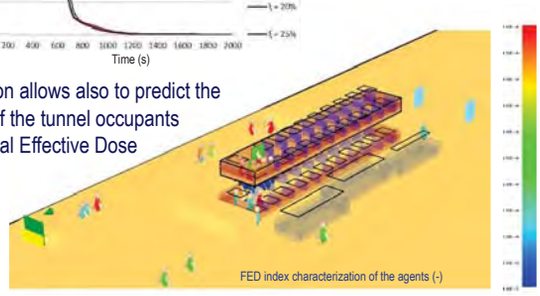


The human perception of smoke was simulated and compared with the mechanical detection time.



The **human perception** of fire anticipates the mechanical detection.

Evacuation simulation allows also to predict the **intoxication level** of the tunnel occupants through the Fractional Effective Dose (FED) index.



FED index characterization of the agents (-)

Conclusions

The World Road Association – PIARC – has defined the road tunnels as "**complex systems**" because of the many different subjects involved in their design and functionality.

The deep relationship between these subjects is clearly underlined by the Condó road tunnel analysis, where the simultaneous simulations of smoke propagation and human behaviour has shown the **toxic effect of smoke exposure** on the tunnel occupants.

This study also highlights how the prescriptive approach (which was used to build the tunnel) **underestimate** important parameters which may influence the evacuation dynamics.

All the involved stakeholders have to take into account numerical simulations, digital and hybrid models, in both design and safety management, in order to build innovative, safe and durable road infrastructures.

Superposition of the AST maps ("digital Condó road tunnel") and real Condó road tunnel