Advanced numerical methods in Fire Safety Engineering

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Introduction to the problem

Due to the fast development of **performance based approach** in fire safety engineering advanced numerical tools are required for more sophisticated analysis. Numerical and semi-analytical methods used in the past by engineers are still valid and widely used in practice. However these simplified models don't provide a comprehensive understanding of the fire scenario, but just some overall results.
In tunnels the **ventilation strategy** is usually designed using one dimensional methods. These are well suited for tunnels' geometries where the flow can be assumed to be one-dimensional, but they don't catch several effects which are fully three dimensional. Jet fans are included with a simplified approach which doesn't take into account the flow field induced by the ventilation device. The throttling effect is usually neglected due to the lack of data for the simplified model.
For **structural analysis** the most common and easiest approach for the verification of structures exposed to fire is the use of pure thermo-mechanical conductive models. For concrete structures moisture and air transport are not taken into account. As thermal input some time-temperature curves are applied as boundary conditions without a direct relation between the thermal load and the specific fire scenario.
To overcome these problems and provide more realistic analysis of the fire scenario Computational Fluid Dynamics (**CFD**) and structural Finite Elements Analysis (**FEA**) can be used.

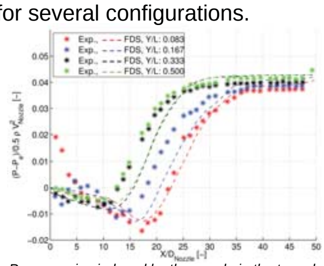
Tunnel ventilation with CFD

Due to the amount of experience and knowledge required to the user to perform reliable calculations, CFD analysis should be always compared with experimental data. In large scale environment, such as tunnels, because of the lack of experimental data and high uncertainties, few validation analysis have been carried out. The CFD code Fire Dynamic Simulator (**FDS**)[1] has been selected for the validation of several ventilation cases both with and without fire.

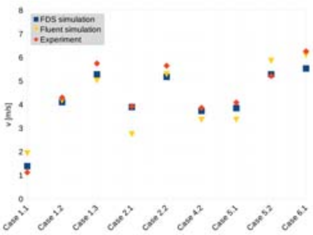

Small scale tunnel experimental by Mutama


Large scale tunnel experiment by Colella

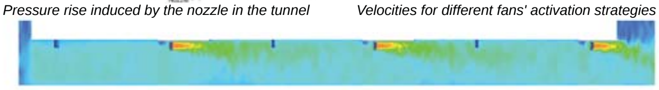
Two experiments in small and big scale were selected for the validation without fire and a schematic view is presented above [2]. In the small scale experiment **pressure** and **velocity** fields induced by a nozzle are compared with the measurements, while in the large scale tunnel the **average velocity** induced by the fans are compared for several configurations.



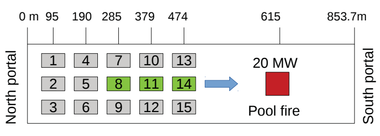
Pressure rise induced by the nozzle in the tunnel



Velocities for different fans' activation strategies

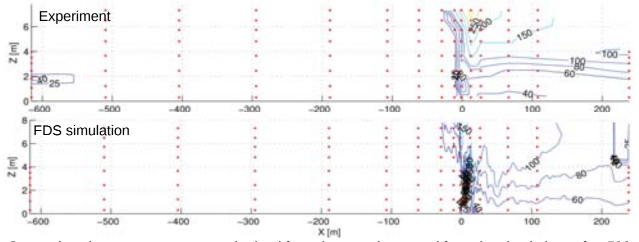

Velocity field induced by the jet fans when only six of the twelve fans are activated.

The Memorial tunnel fire test has been selected to study the longitudinal ventilation in case of fire. A validation in case of fire is required in order to evaluate the capability of FDS to predict the **smoke confinement**.



Ventilation scheme of the fire test no. 608


Entrance of the Memorial tunnel

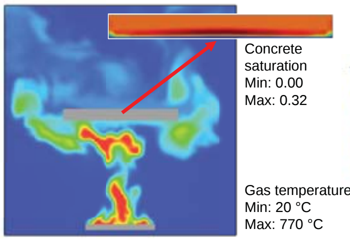


Comparison between temperature obtained from the experiment and from the simulations after 590 s

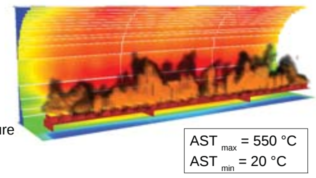
The comparison of several experiments with the simulations shows that FDS is capable to correctly simulate tunnels with longitudinal ventilation both with and without fire. Once FDS is validated it can be used to verify different ventilation strategies and fire scenarios within a small uncertainty range.

Structures on fire with FEA

CFD analysis can be also used to evaluate the **thermal loads** on structures in particular on **concrete structures** [4]. A fully performance based approach is here presented with two examples, a concrete slab exposed to fire and a rail coach on fire in a tunnel [5-6].



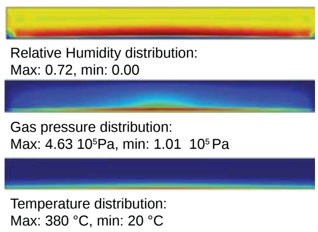
Concrete slab heated by a fire



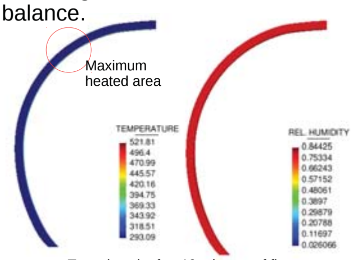
Adiabatic surface temperature distribution in a tunnel


Schematic view of the coach of fire obtained with FDS

With a coupled approach it is possible to transfer the incident heat fluxes obtained with FDS into the FEM code **Comes-HTC** which has been specifically developed for concrete structures at high temperature. From the FEM analysis it is possible to verify the structure using a complex model involving heat and mass transfer coupled with the linear momentum balance.



Slab after 15 minutes of fire



Tunnel vault after 10 minutes of fire

With this approach it is possible to verify the structure starting from a **realistic fire scenario** and without basing on some standard curves. As well Comes-HTC allows to obtain several informations about the structure's behaviour which are not usually available with a standard approach, such as pore pressure and water mass loss.

[1] FDS project web page : https://pages.nist.gov/fds-smv/
[2] M. Pachera, P. Brunello, “Numerical investigation on jet fans for fire control in short tunnels”, *7th International Symposium on Safety and Security in Tunnels (ISTSS 2016),* 2016.
[3] A. Bendelius, "Memorial tunnel fire ventilation test programme" *Seminar Smoke and Critical Velocity in Tunnels*. Vol. 2, 1996.
[4] D. Gawin. F. Pesavento, B.A. Schrefler, “Modelling of hygro-thermal behaviour of concrete at high temperature with thermo-chemical and mechanical material degradation”, *Comput. Methods Appl. Mech. Engrg., (CMAME)*, 192(13-14), pp. 1731-1771, 2003.
[5] M. Pachera, et all, “Combined Approach for High Temperature Concrete Simulations” *11th Conference on Performance-Based Codes and Fire Safety Design Methods,* 2016
[6] F. Pesavento, M. Pachera, P. Brunello, B.A. Schrefler, “Concrete exposed to fire: from fire scenario to structural response”, *Key Engineering Materials, ,DOI 10.428/www.scientific.net/KEM.711.556*, vol. 711, pp 556-563, 2016.