REAL SCALE TUNNEL FIRE: EXPERIMENTAL TEST INSIDE THE MORGEX TUNNEL – AUTOSTRADA A5

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Abstract

The severe fires in Europe, such as those of the Mont Blanc, Gotthard and Tauern tunnels, have clearly displayed the dramatic urgency of adapting the road and rail tunnels to higher safety standards. From 2004 the European directive 2004/54/EC required risk analysis for existing tunnels that are considered below the minimum safety standards. Those Risk analysis procedures have to develop and combine proper models to calculate the flux of danger between the sources and the targets (people, infrastructure and environment), so a key role is nowadays played by computer simulations and fire models. From 2011 the Laboratorio Mobilità e Trasporti and Dipartimento CMIC (Chimica, Materiali Ingegneria Chimica) of the Politecnico di Milano cooperate to improve the knowledge on tunnel fires, using both experimental activity and theoretical tools such as the Fire Dynamics Simulator (FDS) [1]. This code is one of the leading Computational Fluid Dynamics (CFD) models for fire modeling, widely used in the field of fire protection engineering. After the first real event test in the Gran San Bernardo Tunnel, a second real-scale test (15 MW) has been conducted by the team in July 2012 in the Morgex Tunnel, which allowed to collect important measurements and information useful for validating and improving the CFD codes, to obtain a better design of tunnels and their safety systems, to perform risk analysis and to evaluate the best strategies for intervention of rescue teams. The test saw the fundamental cooperation of Corpo Valdostano Vigili del Fuoco and RAV Autostrade SpA.

Introduction

The Laboratorio Mobilità e Trasporti – which is a center of competence of the Italian national civil protection for transportation safety and management and CMIC Department of Politecnico di Milano participate jointly to a modeling and experimental project entitled "Improved CFD models for tunnel fire risk analysis [2]". The idea of the project, financially supported by Politecnico di Milano, stems from a growing awareness at national and European levels to the safety problems related to fires in road and rail tunnels. Fires in tunnels are a threat not just for the safety of users but also for rescue teams. Beside the presence of victims, even the economic consequences related to damages to infrastructure and often prolonged closure of the tunnel must be considered.

To reach the goal of validating and improving the CFD codes, to obtain a better design of tunnels and their security systems, to perform risk analysis and evaluate the best strategies for intervention of rescue teams, it is useful to conduct tests using full-scale structures that can simulate a real event, with known boundary conditions (e.g. geometry, devices and systems installed, etc.). This need has led to a fruitful collaboration between researchers of the Politecnico di Milano, the Corpo Valdostano dei Vigili del Fuoco, and the RAV SpA, manager of the A5 highway in northern Italy (Valle d'Aosta region). On the basis of the previous experience gathered during the training experimental activity performed in the Gran San Bernardo road tunnel [3,4], a new and more complete fire scenario has been designed in the Morgex North tunnel of the A5 Aosta-Monte Bianco highway. In this paper, we describe how the fire scenario was designed and created and present some of the experimental measurements. During the test, it was possible to measure temperature, wind, O_2, CO and PM levels in several locations inside the tunnel. This fire scenario was organized to simulate the fire of a heavy vehicle semi-trailer and thus reproduce conditions similar to the actual emergency situations. Thanks to the presence of a large diesel oil pool fire, able to generate a large amount of dense smoke, it was possible to test the passive safety systems, such as the effectiveness of the ventilation system on the smoke movement.

Project aims and objectives

Three subjects were involved in this real scale fire experiment with different objectives and separate responsibilities, which can be summarized as follows:

Politecnico di Milano:

- Further validation of the CFD code FDS using new experimental data and sensitivity analysis of model predictions to boundary conditions and combustion model

Corpo Valdostano dei Vigili del fuoco:

- Test safety procedures in a tunnel in Valle d'Aosta in case of a relatively large fire (15 MW).
- Gain experience and data during a real fire test, useful to define and improve the intervention procedures.

RAV – Autostrade Spa:

- Test the effectiveness of the ventilation system, using the ventilation setup and performance characteristics described in the risk analysis project of the Morgex North tunnel.

Accident Scenario

The Morgex North tunnel is 2294 meters long and has a width of 10.50 m. The average longitudinal gradient is 3.2%. The accident scenario reproduces the fire of a heavy vehicle (a semi-trailer truck stationary in the right lane), as a consequence of the fire ignition on board of the trailer of the vehicle due to a technical failure and overheating of some mechanical parts. After the ignition, the semi-trailer catches fire, causing a fire with smoke. The roll-off container of Corpo Valdostano dei Vigili del Fuoco (Fig. 1) was used to simulate the aerodynamic effect of the road tractor on the smoke movement. Figure 2 shows the position of the container and the six fire pans used to generate the 15 MW fire inside the tunnel.

Figure 1. Roll-off container used by Corpo Valdostano Vigili del Fuoco to generate smoke in controlled fire conditions.

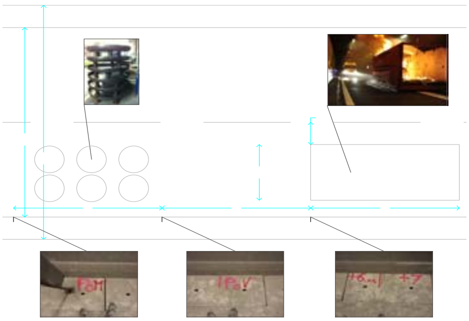

Figure 2. Relative position of the fire pans and the roll-off container.

Fire scenario

The fire scenario was realized using six fire pans filled with diesel oil. Each stainless steel pan has a diameter of 1.2 m and was filled with about 60 liters of fuel. In this way, the six fires were estimated to develop a fire power of approximately 10 MW. The use of a load cell located below the supports of one of the central pans allowed to measure the instantaneous weight loss during the various stages of the fire development (ignition, development, extinction). In this way, the average and instantaneous fire power can be calculated. Figure 3 shows the fire pans and the insulation material used to protect the road to avoid overheating and damage of the asphalt pavement. It is important to notice that one of the major difficulties in the preparation of this fire test was associated to the fact that the tunnel is part of an important highway, which connects northern Italy with the Mont Blanc tunnel. For this reason, the tunnel remained in operation also during the construction works needed to prepare the insulation in the fire region (only the right lane was temporary closed) and to install the metal poles where thermocouples, anemometers and other instruments were installed. Efforts were made to define a fire scenario able to comply with the safety requirements and the need of a very rapid preparation and disassembling of the scenario. In fact, the tunnel remained completely closed only for some hours during the night between 2 and 3 July, 2012. Thanks to the careful preparation, the proper use of insulation

material and the efficiency of the ventilation system, the tunnel was not damaged by the fire heat and smoke, and was open to the traffic immediately after the test.
To design the fire scenario, we used literature correlations which provide the diesel oil burning velocity (kg/m^2/s) as a function of the diameter of the pool fires.

Table 1. Parameters of the $m = m_\infty \cdot \left(1 - e^{-k'D}\right)$ correlation.

$m_\infty \left[\frac{kg}{m^2 \cdot s}\right]$	k'	Reference
0.0555	0.935	Used in this work
0.054	1.30	Rew et al. [Process Safety Environ. Protect. 75:81–89 (1997)]
0.057	0.57	Chartis et al. [Combustion and Flame 126:1373–1383 (2001)]
0.034	2.8	Babrauskas [Fire Technol. 19:251–261 (1983)]

Figure 3. Fire pans located in the fire region where insulation material protects the asphalt preventing overheating. Metal poles with instruments are also protected.

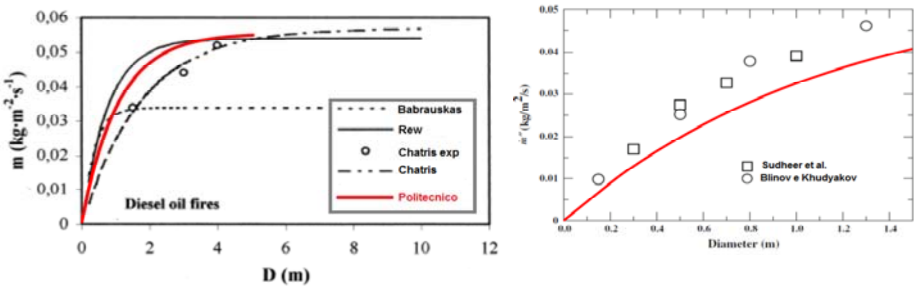

Figure 4. Comparison of experimental data [adapted from Chartis et al., Combustion and Flame 2001 and Sudheer et al., Fire Technology, 48, 183–217, 2012], literature correlations and the value used to define the fire scenario (Politecnico).

These correlations give the fire power as a function of the pool diameter, but they refer to isolated fires and are not able to take into account the interactions. In our experiment six pans are located one close to the other, therefore we expected these correlations to underestimate the fire power. The literature parameters of the correlations are shown in table 1. Figure 4 shows a comparison between the different correlations and literature experimental results. It is evident that the specific burning rate of large pools is larger than the one of small fires. Using the correlation of table 1 we estimated a total fire power of 10 MW. The measurements allowed to calculate that the actual fire power was 15 MW. The difference is largely a consequence of the interaction between the pools which was clearly observed during the test.

Experimental Measurements

Two different fire scenarios were tested.

- Case 1: using 9 ventilators (expected air velocity > 5.0 m/s);
- Case 2: using 5 ventilators (expected air velocity > 2.5 m/s);

The activity involved the measurement of the following quantities:

- air (smoke) temperature and speed
- composition (O_2; CO; NO; NO_2; SO_2; LEL; CL_2; HCN; NH_3)
- particulate matter and particle size distribution.
- opacity

Figure 5. Experimental devices: data logger, thermocouple and anemometer.

Table 2. Measurement Locations

A	- 440 m
B	- 50 m
C	- 20 m
D	-5 m
E	0 m (fire)
F	+ 3,5 m
G	+ 7 m
H	+ 9 m
I	+ 15 m
L	+ 30 m
M	+ 50 m
N	+ 100 m
O	+ 150 m
P	+ 195 m

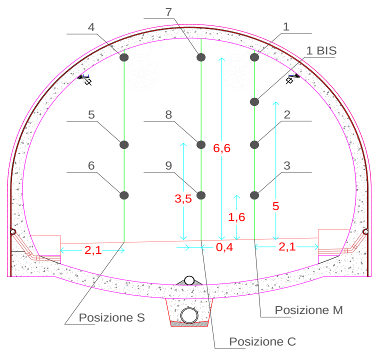

Figure 6. Distribution of thermocouples and other devices in one section.

Figure 5 shows an example of the instruments and data loggers used during the activity. On the basis of preliminary calculations, in agreement with the RAV personnel and following the firefighters suggestions, we identified different tunnel sections were thermocouples trees and other instruments were located. These sections cover a large part of the tunnel, above and after the fire zone. In particular, thermocouple trees were positioned to measure the vertical (from typical human height up to the ceiling) and transverse temperature profiles at several locations as

show in Table 2 and Figure 6.
Figure 7 shows some pictures taken during the fire development. The smoke backlayering (visible in the central picture) completely disappeared after the activation of the ventilation system which increased the air speed. Figure 8 shows some of the measurements made during the campaign.

Figure 7. Fire pictures: single pan fire (left), initial smoke backlayering (center) and firefighters during the activity (right).

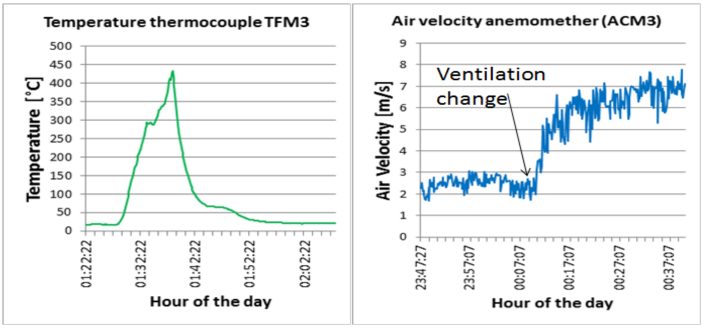

Figure 8. Temperature and air speed were measured in several locations during the fire test.

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