COMPUTATIONAL SIMULATION OF ROAD TUNNEL FIRE PROTECTION, BY USING SPRINKLERS

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The present article proposes a relatively new method of protection of certain areas of the road tunnels, with sprinklers using water as an extinguishing agent. The simulation uses as input an architecture as close to that of a real road tunnel as well as information gathered from the literature and the results can be implemented for proposals on the protection of users, as a viable alternative when other classis fire fighting or spread flames blocking methods can't be used at full scale. The paper focuses on presenting and studying the effect of protection and curtain that can be issued by the sprinkler network water droplets and the information resulting from the simulation.

Keywords: road tunnel fire, sprinklers network, fire simulation, water droplets

1. Introduction

Road tunnels are special parts of road traffic infrastructure when it comes to fire safety. These special objectives need to be protected in case of fire. In a road tunnel the main concern is the protection of its users. This is why sprinkler water droplets will be used both to directly extinguish the fire and to create a safer evacuation path. Nowadays, in the world, constructions such as road tunnels are designed, built and used considering the fire safety engineering principles, standards and concepts.

In reality and in the literature are presented a lot of situations where water or water mist fire sprinklers are used to protect spaces similar to road tunnels, underground tunnels or for other confined closed spaces [1-3].

Sprinkler is an active fire protection device discharging water in order to extinguish the fire. In road tunnels electricity maybe used to power the auxiliary systems (lighting, video surveillance, traffic control) which would disagree concerning the use of these sprinklers, as water is involved in conducting electricity. Still, according to the national regulations, in a fire or another emergency situation, the electricity should be automatically disconnected and the

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auxiliary systems above mentioned should have protection against water infiltration [4].

As stated above, the main concern of fire safety is evacuation of people. In order to protect people in case of evacuation, one need is to protect them from smoke and hot and toxic gases, the evacuation paths.

In order to avoid a fire occurring or to limit its negative consequences, measures including jet fan mounting and active fire fighting technical equipment are priority to be taken and followed, in 500 m or long road tunnels, according to specific law.

With these considerations in view, the tunnel ventilation may take use of the following measurements [5]: fast and safe users evacuation, concentration of different fire effluents as close to the tunnel exhaust as possible, proper utilization of the extinguishing agents, even if it is about water, foam or other substance used in this purpose, maintaining a proper vehicle speed and traffic flow in each tunnel section and compliance of minimum safety distances between vehicles, ventilation system and active fire fighting measures [6].

In the present paper, authors use fire simulations as a tool to study the effectiveness of such a protection method. More protection devices will be used in a virtual fire simulation of a fire in a road tunnel (random consider), to protect the evacuation route (both tunnel exists, in this case) from smoke and hot toxic gases, by forming a water droplets barrier.

Still, as air currents are quite powerful in such open areas, data is collected from the literature of a real road tunnel fire scenario that served as a model and implemented into the simulation. Basically, the interactions between smoke and water droplets in the protection curtain formed by sprinklers will be studied.

Based on the above mentioned findings, this article aims to analyse some of the circumstances conditions and active measures which can be applied due to a fire taking place in a road tunnel, using Pyrosim (a software program based on FDS platform) in order to simulate a real fire event and estimate its probabilistic evolution in predetermined conditions, with appropriate protection measures.

2. FDS, fire simulation software

FDS (Fire Dynamics Simulator), a software developed by NIST (The National Institute of Standards and Technology – U.S.A.), is a computer programme of fluid dynamic simulation, particularly of the heat flow released during a fire; it uses the high definition computer language “Fortran 90” and solves the governing equations of fire dynamics. “Smokeview” program, written in “C/OpenGL” is the pair program that produces images and animation of the results.

Mathematical model adopted by the software is adapted on the fire development in which the fluid dynamics, the heat transfer and combustion occur. FDS computes the temperature, density, pressure, velocity and chemical composition within each numerical grid cell at each discrete time step. In addition, FDS computes on the solid surfaces the temperature, heat flux, mass loss rate and various other quantities [5-7].

Typical output quantities for the gas phase include: gas temperature, gas velocity, gas species concentration (water vapours, CO_2, CO, N_2), smoke flying particles and visibility estimation, space pressure, heat release rate per volume unit, mixture fraction (or air/fuel ratio), gas density, water droplet mass per unit volume contained in the atmospheric moisture, the walls and sprayed particles.

For successfully using the computer modelling, is enough to understand the basic laws of mass, momentum and energy conservation for Newtonian fluids as they are presented below:

Conservation of mass:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot \rho \mathbf{u} = \dot{m}_b''' \quad , \tag{1}$$

with: ρ density in [g/cm³]; t the time in [s] ; u velocity in [m/s]; $\dot{m}_b'''$ the net heat flux from thermal conduction and radiation in [kg/s/m^3].

Conservation of momentum (Newton's second law):

$$\frac{\partial}{\partial t}(\rho \mathbf{u}) + \nabla \cdot \rho \mathbf{u}\mathbf{u} + \nabla p = \rho \mathbf{g} + \mathbf{f}_b + \nabla \cdot \tau_{ij} \quad , \tag{2}$$

with: p pressure in [Pa]; g the gravity vector acceleration in [m/s^2]; $\mathbf{f}_b$ the external force in [N/m^3] and τ_{ij} stress tensor in [N/m^2].

Conservation of energy (first law of thermodynamics):

$$\frac{\partial}{\partial t}(\rho h) + \nabla \cdot \rho h \mathbf{u} = \frac{Dp}{Dt} + \dot{q}''' - \dot{q}_b''' - \nabla \cdot \dot{\mathbf{q}}'' + \varepsilon \quad , \tag{3}$$

with: h the enthalpy in [J/kg]; $\dot{q}'''$ heat release rate per unit volume in [W/m^3]; $\dot{q}_b'''$ the energy transferred to the evaporating droplets in [W/m^3]; $\dot{\mathbf{q}}''$ the heat flux vector in [W/m^2] and ε the dissipation rate in [W/m^3].

The accuracy of this modelling confirmed a high precision of computer modelling and was admitted for its usefulness and its applicability.

3. Input data used in fire simulations

The geometry of the virtual space is similar to a real road tunnel in Romania, as example. The geometrical data of the road tunnel is presented in table 1 and different views of the layout in FDS/ Pyrosim are shown in figure 1 and 2.

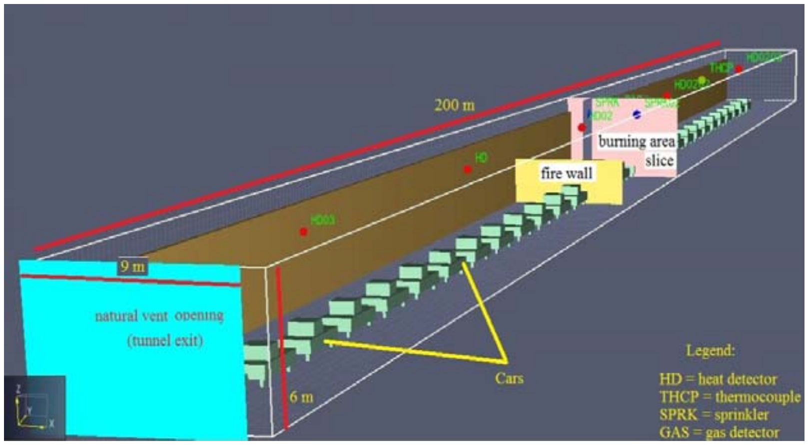

Fig. 1. General architecture of the road tunnel, with cars and protection devices, imported in FDS

Table 1

Input data in Pyrosim for road tunnel fire and the protection of the tunnel users

Category	Parameters	Value
Computational domain	Simulation volume	Road tunnel, designed in the program, by taking geometrical data from a random real road tunnel
	Dimension of the volume containing subway station	200 m x 9 m x 6 m (in order on 0x, 0y and 0z axis)
Numerical data	Cells per mesh, uniform division	240 x 60 x 48 cells
	Dimension of one cell	0,5 m x 0,5 m x 0,5 m
	The total number of cells	98.688
	Boundary conditions for the simulation volume	The boundary of the domain was considered closed, except for the limit maximum x0y, which was considered open. The whole structure of the road tunnel was considered of concrete.
Other data	The fire burner	Imported from the FDS library, HRR (heat release rate) of 1.500 kW/m^2, square shape fire source, dimensions 0,9 m x 0,8 m
	Environment values	20 °C, relative humidity 40 %, atmospheric pressure 101.325 Pa, ground level at 1.500 m about sea level .
	Simulation time	200 seconds
	Sprinklers	Imported from FDS, flow 1liter/minute, k factor = 1, droplet median diameter 100 µm
	Fan - wind current generator	Both tunnel exists, measuring 9 m x 6 m

There were also inserted devices as follow: gas detector, 5 heat detectors, 1 thermocouple and 2 sprinklers with a flow rate of 1 liter/minute and a droplet mean diameter of 100 μm. All the devices were inserted at approximately equal distances from the burning zone [8].

Fire scenario: it is considered that the fire occur at one stationary car caught inside the tunnel, at the half of the tunnel length (100 m from each of the exists) due to an electrical fault at its engine. The car is about 4 m long, 1,5 m high and 1,5 m width, being made of steel, with its predefined physicochemical properties chosen from the program values. There are 30 similar cars in the tunnel, with 1,5 m between them.

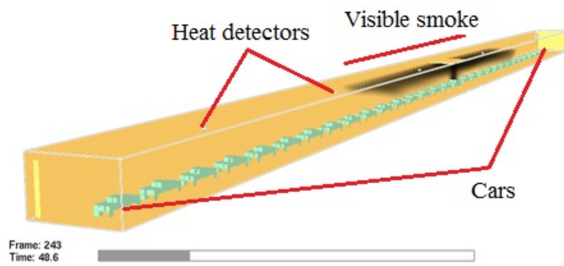

Fig. 2. Visible smoke, filling the upper half of the tunnel after almost 50 seconds of simulation

The fire burner used in the simulation has a heat release rate of 1.500 kW/m^2, with a plane area of 0,72 m^2 [9-10]. The amount of smoke generated is automatically calculated by the program and the user has also the possibility to view it as smoke dissipation along the upper half of the road tunnel, as shown in figure 2.

The smoke dissipation shown in the figure 2 reveals that the smoke spread at more than 50 m each side of the burning car, going down to 2,5 m height, which become dangerous for the tunnel users, after 50 seconds from the simulation beginning.

According to the simulation data, the temperature fields develops the gradient on the vertical up to 370 °C at around 4,5 m height [11]. Also on the ceiling of the tunnel, highest than 5,5 m, the temperature reaches 300 °C, for an approximately length of 30 cm, around the fire core.

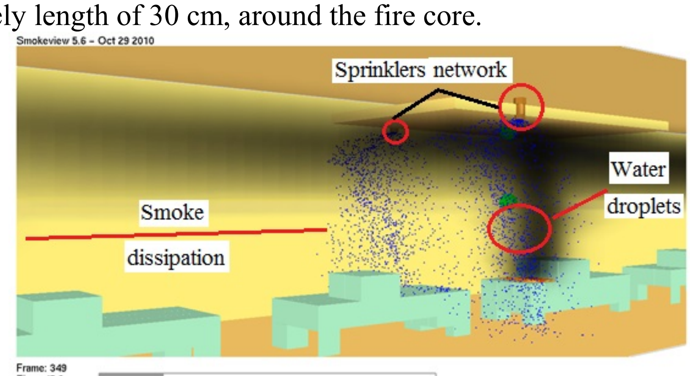

Fig. 3. Smoke and water visible as particles

The sprinklers are placed at the ceiling of the tunnel, measuring 7 m between them, on the O_x axis. The diameter of the spreading water droplets area is 4,5 m around the burning zone. According to this, the sprinklers start working after 4,6 seconds, when the trigger temperature of 65 °C is reached. After 50 seconds of simulation, the fire is completely extinguished, at which point the smoke fill almost entirely the upper half of the road tunnel.

As it can be seen in the figure 3, the water droplets generated by the sprinklers network successfully dissipate the smoke around them, thus maintaining better visibility and decreasing the chance of backfiring, by decreasing the O_2 level and giving a lower temperature around them.

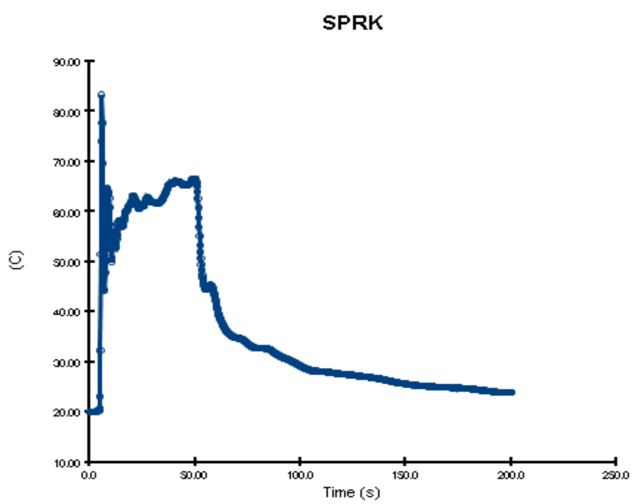

Fig. 4. Temperature reaches at the sprinklers level

As it can be seen in figure 4, the highest temperature reached around the sprinklers network is in the first 10 seconds of simulation, about 83 °C, this decreasing to almost 65 °C during the fire action and also decreasing to almost 20 °C by the end of the simulation.

Sprinklers used in fire simulation are placed as seen in figure 2, in order to produce a protection water curtain. The curtain is intended to protect people and evacuation route, from smoke but also from heat. Throughout the space, mainly on evacuation routes are placed virtual temperature thermocouples and smoke detectors, virtual devices that give information concerning the simulated values of temperature or smoke density in a specific point, as a function of time.

The main objective of the paper is not to study the exact amount of different values for the simulation.

4. Conclusions

Authors used fire simulations in order to come up with conclusions concerning the effectiveness of water sprinkler curtain protection against fires, in road tunnel fire simulations. The total fire time is about 45 seconds after it was extinguished by the sprinklers. This range of values allows checking the air circulation in the studied tunnel in aim to avoid the disagreeable values for traffic and life protection in road tunnels construction. Also, it has been shown that the smoke spread very fast at long distances, which may affect the users before they can be evacuated.

Although there were used only 2 sprinklers places at a relatively small distance between them, it can be revealed that the water droplets generated by the sprinklers network successfully dissipate the smoke around them, thus maintaining better visibility and decreasing the chance of backfiring, by decreasing the O_2 level and allowing a lower temperature around them. Most important, the water droplets are successfully extinguishing the fire. All above mentioned combined together prove that, at a real scale, with a more complex sprinkler network placed entirely tunnel length, the extinguishing action and thus saving users, by maintaining a lower temperature and a better visibility, would be more streamlined than without using a sprinkler network.

The article reveal the importance of using sprinklers, without the effects of a fire event occurring in a road tunnel would be more severe for users, material and environment.

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