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VENTILATION AND FIRE PROTECTION OF ROAD TRAFFIC TUNNEL

VENTILACIJA I PROTIVPOŽARNA ZAŠTITA SAOBRAĆAJNOG PUTNOG TUNELA

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Keywords
- road traffic tunnel
- ventilation, fire
- smoke control
- numerical simulations
- in-house software

Abstract

The main aim of this paper is focused on the ventilation system in a road traffic tunnel in the moment of an accident situation as a fire. The paper gives an overview of the innovative approach in a field of planning and fire protection of the road traffic tunnel. During the planning and design of the ventilation system, it is important to take in account the fire intensity and it is necessary to provide safe evacuation of people from the tunnel tube. One of the main requirements of a ventilation system is to be able to provide the necessary - critical speed of air flow from the fan to prevent smoke penetration along the zone of passenger evacuation. For this purpose, software has been developed to provide necessary conditions and requirements in accordance with the geometry of the tunnel tube and dispositions of fans inside the tunnel. This paper presents the numerical simulation of fire, and a critical air velocity depending on the intensity of the fire, as well as the output software results developed for this purpose, that are used in the realization of practical projects.

Ključne reči
- putni saobraćajni tunel
- ventilacija, požar
- odimljavanje
- numeričke simulacije
- 'in-house' softver

Izvod

Pažnja u radu usmerena je na rad ventilacionog sistema u putnom saobraćajnom tunelu u slučaju požara. U radu je dat prikaz naše inovativne usluge, a to je projektovanje ventilacije i protivpožarne zaštite putnog saobraćajnog tunela. Pri projektovanju ventilacije tunela definiše se snaga požara za koji ventilacioni sistem mora da bude projektovan da obezbedi bezbednu evakuaciju putnika u slučaju požara u tunelskoj cevi. Jedan od primarnih zahteva kod ventilacionog sistema je da bude sposoban da obezbedi potrebnu – kritičnu brzinu strujanja vazduha od ventilatora za sprečavanje prodora dima duž zone evakuacije putnika. Za tu svrhu razvijen je odgovarajući softver kojim se za datu geometriju tunelske cevi i dispozicije ventilatora u tunelskoj cevi obezbeđuju potrebni uslovi i zahtevi rada ventilacionog sistema. U radu su date numeričke simulacije požara, odnosno, potrebna kritična brzina strujanja vazduha u zavisnosti od snage požara, kao i izlazni rezultati razvijenog softverskog paketa za tu svrhu, koji se koristi prilikom realizacije konkretnih projekata.

INTRODUCTION

Designing the road traffic tunnel is a very complex and interdisciplinary approach. One of these requirements is the project of the ventilation system in tunnels and is the subject of this paper /1/. Here are considered tunnels with longitudinal ventilation. A major characteristic of this type of ventilation is dominantly air flow with the correlation of working equipment to match with the longitudinal axis of the tunnel. Basically, the ventilation system can be analysed in regular and incidental modes of operation. In the regular mode, the role of ventilation system is to obtain quality air inside the tunnel tube, or to provide the allowed value of harmful gases emitted by vehicles. This is primarily related to carbon monoxide CO and NO_x sodium oxides.

As part of the development of a certain region and beyond, roads occupy a special location. Particularly, in Serbia are road corridors 10 and 11, the modernization of the railway infrastructure, the highway Niš-Drač, the metro in the city of Belgrade, the Fruška Gora corridor and others. Each of the aforementioned traffic roads has tunnels in its individual parts. In the framework of safety, an important part is controlling the operation of the ventilation system in all regular and critical (e.g. fires) traffic modes in tunnels.

According to our knowledge, authorised design companies in our country do not have complete software (they are of local character and are not available on the market) and do not correspond to procedures for managing the automatic operation of the ventilating system in a regular fire mode for analysis of critical situations in tunnels, and for various fire locations along the tunnel tube /3, 4/. This can be solved with a developed software solution. In the past, these problems were analysed by using empirical methods consisting of developed fire situations with different fire intensities and then by monitoring the amount of fumes (Fig.1), and smoke dispersion. Experimental results found around the world are obtained by burning vehicles with different fire intensities and with positioned encoders for measuring the required parameters and collecting experimental results and parameters, required for designing ventilation systems.

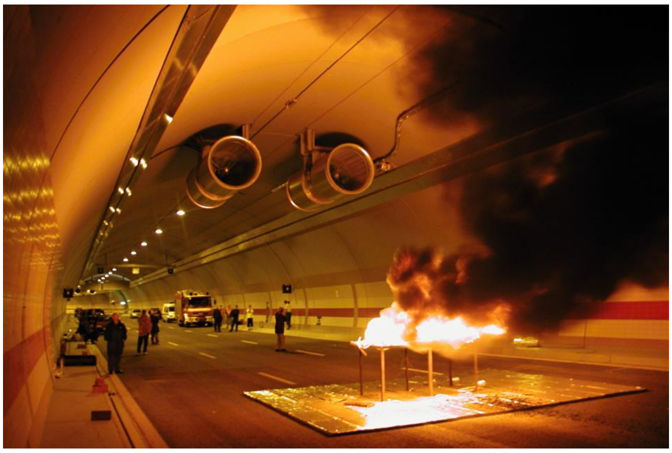


Figure 1. Dispersion of fire smoke inside a road tunnel.

Now, the use of this software solution enables obtaining parameters for automatic control of the ventilation system instead of experimental testing each situation and intensity of fire. Operation of the ventilation system in conditions of a fire incident can be introduced today under the generally accepted unique term ‘operational strategy’ /4/ of the ventilation system operation. In some European countries, regulations stipulate minimum rates of fresh air flow that the ventilation system must be able to provide primarily for situations in incidental mode /5-7/. RABT is the German regulation for single-mode traffic /8/ and defines that the minimum rate of fresh air should not exceed the critical smoke control rate. The Austrian standard RVS 09.02.319 prescribes that the ventilation system for longitudinal ventilation should be able to reduce the flow rate in one-way traffic air between 1.5 m/s to 2 m/s, and for bi-directional traffic to a value between 1 m/s to 1.5 m/s. In the meantime, it has been accepted by professional organisations and bodies, PIARC /5/, as the world’s leading organisation in the field of road transport.

NUMERICAL SIMULATIONS

In the incident situation (fire situation) in the traffic road tunnel, a large amount of smoke is generated depending on the fire intensity. Depending on the location of fire in the tunnel tube it is necessary to activate the ventilation system in such a way to prevent smoke penetration from the fire location along the evacuation zone without compromising the safety of the passengers on the other side of the fire. For this purpose, it is necessary to design the operation of the ventilation system in the situation of fire in such a way as to prevent smoke penetration into the passenger evacuation zone. Here, the software package FLUENT®, based on CFD (Computational Fluid Dynamics) analysis, is used for modelling the fire in tunnels. Concerning the dependence of fire intensity here, it is important to define the ventilation system operation. The main goal in this paper is to define automatic operations of the ventilating system that performs the smoke extraction, in the first stage (phase) of fire.

The role of the ventilation system in traffic road tunnels is to:

1. In regular traffic mode to provide the required air quality contaminated by exhaust gases of a vehicle and,
2. In an emergency mode, or in the situation of a fire, the ventilation system shall provide the required air flow rate to prevent the smoke penetration in the evacuation zone of the passenger.

Numerical simulations of air flow by the ventilation system in a regular traffic mode may be performed with commercial software packages, such as FLUENT®, in conjunction with ‘in-house’ software.

However, in the situation of a fire, it is necessary to model the fire of certain intensity from which smoke extends at a certain flow rate. In the situation of a fire, the ventilation system must provide the air flow rate velocity that prevents the smoke from entering toward the passenger evacuation zone. It is precisely, within this paper, to define this speed- the critical flow velocity of smoke inside the tunnel tube. This speed basically depends on: the intensity of the fire - Q, the light cross-section of the tunnel tube - FT, the height of the tunnel tube - H, as a characteristic of the fluid flow in the fire zone.

Procedures that define the operation of the ventilation system are incorporated into our software (in-house software), according to the intensity and location of the fire along the tunnel tube. European norms and directives /2/ must be respected in the case of fire and risk analysis.

These norms and directives define the safety requirements, including safety requirements for fire in traffic road tunnels. Speaking of fire in tunnels, first of all it is important to precisely define working operations of the ventilation system, to prevent smoke penetration in the passenger evacuation zone. Table 1 shows the modes of fire (fire intensity) in the situation of different types of vehicles in fire.

Table 1. Models of fire in tunnels.

Type of fire	Calorific energy [MW]	Maximum temperature [°C]	Amount of smoke [m^3/s]
passenger vehicle	5	400	20
bus / truck	20 to 30	700	60
fuel tank	100	1000	100-120

The critical flow velocity, V_c, that is necessary to prevent the movement of smoke from the point location of fire (Fig. 2) is contrary to the air flow produced by fans, depends on several parameters:

$$V_c = f(Q, T_f, T_0, F_T, C_p, \rho_0, H, i...)$$

where: Q-intensity of fire; T_f-temperature at the point location of fire; T_0 -air temperature inside the tunnel outside of the fire location; F_T - cross-sectional surface of the tunnel; C_p -specific heat at constant air pressure outside the fire zone; ρ_0 - density of the air inside the tunnel, outside the fire zone; H-tunnel height; and the i-th gradient of the path inside the tunnel.

DETERMINATION OF CRITICAL AIR SPEED INSIDE THE TUNNEL TUBE

The concept of a critical velocity to control the upstream movement of smoke inside tunnels has been available for many decades. This paper represents an effort towards quantifying the critical velocity by providing analytical solutions for its value inside tunnels. Several analytical - empirical expressions for determining the critical air speed value are used here. One of frequently used analytical equations is by Danziger and Kennedy, /6/,

$$V_c = K_1 K_2 \left(\frac{gQH}{\rho_0 T_f c_p A} \right)^{1/3}, \tag{1}$$

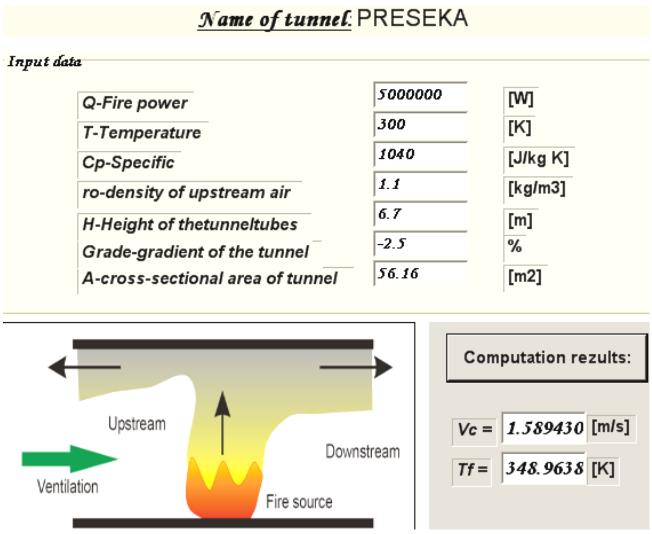
where: coefficients K_1 and K_2 are defined as,

$$K_1 = Fr_c^{-1/3}, \tag{2}$$

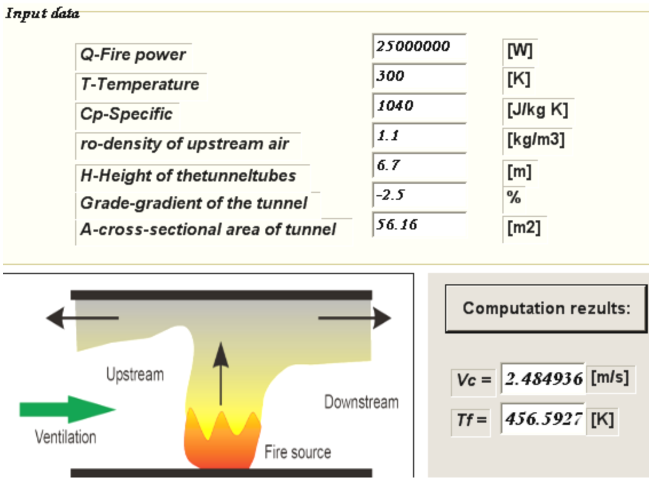
$$K_2 = 1 + 0.037(\text{grade})^{0.8}, \tag{3}$$

and average smoke temperature,

$$T_f = \frac{Q}{\rho_0 c_p A V_c} + T_0, \tag{4}$$



(a) passenger vehicle in fire



b) Bus / truck in fire

Figure 2. Simulation results of fire in a tunnel tube obtained by software package for fire intensities of: a) 5 MW; and b) 25 MW.

where: Q-thermal fire intensity; H-height of the tunnel tube; T_0-temperature of incoming air inside the tunnel tube; c_p-specific heat of the air; A-cross-section surface of the tunnel tube; (grade)-gradient of the tunnel in percent; Fr_c - the critical Froude number and inclination which is the gradient of the path inside the tunnel, expressed in percent.

Equations (1) and (4) represent a coupled system because both represent V_c, and some of the iterative methods should be used. The software package 'FIRE' is used for calculating the critical flow velocity, V_c, that needs to be provided by the ventilating system. This software package is intended for fire simulations in different types of tunnels (with two tunnel tubes, one tube, or one-way (one direction) and two-way (two directions) traffic, as well as for different ventilating systems).

Critical air velocity, V_c, produced by fans, is aimed to prevent smoke penetration into the passenger evacuation zone and is one of the most important parameters that should be provided by the ventilating system in situations of fire.

In Fig. 2 are shown the results of the calculation for the critical speed of fresh air flow, V_c, that should be provided by the ventilating system in case of fire from a burning passenger vehicle (Fig. 2a), as well as in case of a fire from a burning truck/bus (Fig. 2b) inside the tunnel tube. The impact (dependence) of fire intensity Q on the required critical speed value V_c is evident.

Table 2. Dependency of critical speed (V_c) with fire intensity (Q).

Q [MW]	5	10	20	25	30	40	50
V_c [m/s]	1.59	1.95	2.35	2.48	2.59	2.78	2.91

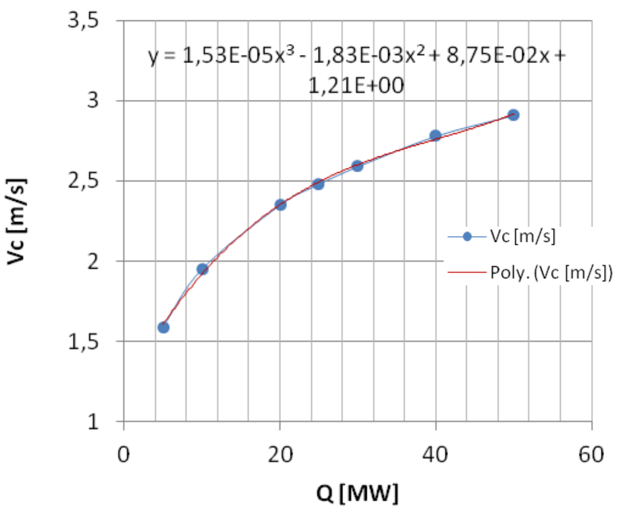


Figure 3. Critical velocity approximation using a third-degree polynomial.

Using the dependence between fire intensity Q of critical velocity, given in Table 2 and in Fig. 3, an analytical expression for the dependence $V_c = f(Q)$ is formed as in the following relation:

$$V_c = 1.53 \cdot 10^{-5} Q^3 - 1.83 \cdot 10^{-3} Q^2 + 8.75 \cdot 10^{-2} Q + 1.21. \tag{5}$$

The Eq.(5) has a general character and can be used to define the critical speed which should be provided by the ventilation system in the tunnel tube.

CONCLUSION

Primary attention in this paper is focused on determining the critical value of fresh air flow speed which should be provided by the ventilation system in a fire situation in the traffic road tunnel tube. For this purpose an 'in-house' software package 'FIRE' is developed, with the main goal to determine the critical speed, depending on the intensity of fire, on one side, as well as the geometrical characteristic of the tunnel and the state of the fluid in the fire zone in the tunnel, on the other side. Beside the critical speed, this software allows to calculate the air temperature in the fire zone. Special attention of this research is focused on the choice of the ventilation system and its automatic operation in a fire situation of various intensities of fires occurring at any location in the tunnel tube, and its capabilities to provide the critical speed of fresh air flowing towards the fire zone. For this purpose, a general analytical expression has been formed for the dependence between the critical speed and the fire intensity in the tunnel tube.

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