8th International Multidisciplinary Symposium

„Challenges and opportunities for sustainable development through quality and innovation in engineering and research management”

UNIVERSITARIA SIMPRO 2018

Dynamics of spread of fire-related harmful factors in metro tunnels during a forced stoppage of the metro train

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Abstract

The present work deals with emergency situations which develop as a result of 30 MW-magnitude fires that may occur for various reasons within the metro (subway) tunnel infrastructure. The article will produce numerical modelling of the emergency situation within the PyroSim 2016 programme environment. It will offer a base model of the emergency situation for the following tunnel geometry: cross-sectional area of the tunnel – 20 m^2; length of the tunnel – 800 m; volumetric efficiency of the tunnel – 0,375; length of the metro train – 80 m; cross-sectional area of the train – 7.5 m^2. The article will explore the changing dynamics of the harmful factors (temperature, carbon monoxide, carbon dioxide and oxygen concentration levels) which develop in portals along the tunnel as a result of fires. The boundary conditions for various ventilation flows will be examined. We will study the effect of the location of the train and the fire on the dynamics of spread of harmful factors as a result of stoppage of the train inside the metro tunnel. The modelling process will determine the required time parameters for safe self-evacuation in an emergency situation. It can be used for the quick planning and implementation of emergency assistance activiti*es.*

Kaywords Metro tunnel, fire, Hurmful factors, numerical modelling

1. Introduction

Underground transport (metro) represents the fastest-growing transport network in global megalopolises. The metro has a history of approximately 150 years. The total length of underground metro networks across the world is 15 000 km, of which 5000 km have been constructed during the past 15 years. Existing networks are being expanded and reconstructed, while elsewhere, new subway transport centres are being established. Security of the underground transport system is particularly sensitive with regards to fire safety. This is primarily due to the shortage of evacuation options during fires in the metro, as well as the difficulty of the evacuation process scenario. Statistics of the main causes of fire in the metro (Long Poon and Richard Lau, 2007) is presented in the form of a circle diagram (see Fig. 1).

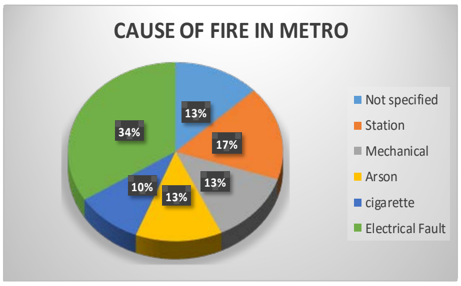

Fig. 1. Statistic data of the causes of fires in the metro

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Based on the given statistics, approximately 17% of the metro fires occur at the stations and in areas adjacent to the stations, while the remaining 83% are accounted for by metro tunnels, where fire safety and evacuation activities are more difficult to implement than at the stations.

These instances usually lead to the stoppage of the metro train and the start of the self-evacuation process towards a free portal inside the tunnel.

During the last 30-35 years, there have been several cases of catastrophic fires occurring in the subway and funicular transportation systems. Although these were not particularly powerful fires, they all had disastrous results. For example, the Baku Metro fire in Azerbaijan killed 337 people in 1995, while 155 people died in Kaprun (Austria) in 2000, and 198 people in Daegu (South Korea) in 2003.

The aforementioned cases have all got several common characteristics: The materials involved in the fires were characterised by flammability and high toxicity of the substances released during the fire;The metro train was forced to come to halt inside the tunnel (Baku, Kaprun), or did not leave the station (Daegu);

The majority of the victims were poisoned by toxic gases.

- The complexity of the causes of fire.
- The absolute majority of metro systems use a high-voltage electrical power system. Statistics show Fig. 1. that electrical faults constitute the most common cause of fires today.

Fires in the metro can be subdivided into the following two categories:

- Fires in the metro's power supply infrastructure;
- Fires in the metro's metro train.

In present article we study fire in metro's power supply infrastructure.

1. Task of numerical modelling

2.1 Initial Conditions

In the present study we do numerical modelling of possible fire scenarios in the metro's power supply system, using the tunnels of the Tbilisi metro as an example. The geometric data of the tunnel and the metro train is presented below:

- Length of the tunnel – L_t=800 m; cross-sectional area of the tunnel – S_t = 20 m^2; length of the train – L_{tr} = 80 m; cross-sectional area of the train – S_{tr} = 7.5 m^2; the location of the halted train is measured from the left-hand portal, using the coordinates $X_{tr\ 1}$ and $X_{tr.\ 2}$, whereby $X_{tr.\ 2} = X_{tr.\ 1} + L_{tr}$; fire location –$X_F$; location of the tunnel air shaft – X_S = 400 m from the left-hand portal; cross-sectional area of the shaft – S_i = 1, 4, 9 m^2; surface area of the burn – S_F ; general formula for the burn reaction type – $C_xO_yH_zN_r$, the carbon compounds used in the high-molecular electric isolation material are modelled on the simple reaction of burning polyurethane, with the average carbon monoxide share of 0.2 g/g (Sean Thomas McKenna and Terence Richard Hull, 2016).The location of the halted train is measured from the left-hand portal, and the modelled cases are: $X_{tr\ 1}$ =202 m, 302 m, 351 m, 402 m, 502 m, 602 m. The fire source is located at the X_F = 700 m mark from the left-hand portal. The modelled cases are classified as follows, depending on the position with respect to the air shaft (see Fig.2.):

$$\begin{aligned} &- \quad X_{tr\ 1},\ X_{tr.\ 2} < X_S < X_F; && X_{tr\ 1} = 202\ m.,\ 302\ m. \\ &- \quad X_{tr\ 1} < X_S < X_{tr.\ 2} < X_F; && X_{tr\ 1} = 351\ m., \\ &- \quad X_S < X_{tr.\ 1},\ X_{tr.\ 2} < X_F && X_{tr\ 1} = 402\ m,\ 502\ m,\ 602\ m. \end{aligned} \tag{1}$$

2.2 Boundary Conditions

The flow of heat from the fire and the boundary conditions for the ventilation flow are presented in Fig. 2.

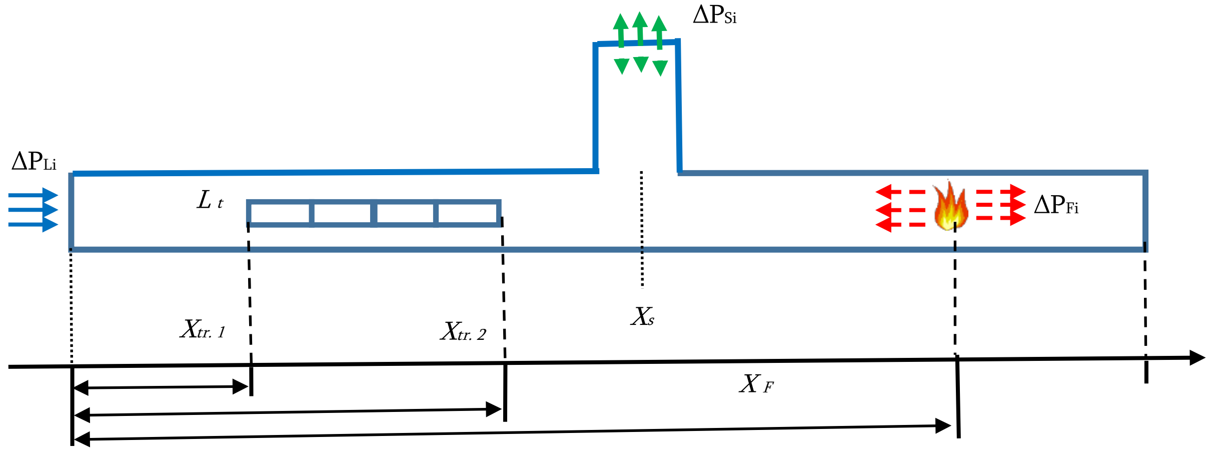

Fig. 2. An emergency situation model of a forced stop of a train during infrastructural fires in a subway tunnel.

The dynamic pressure from the ventilation flow in the left-hand portal is modelled as the difference in pressure between the portals – ΔP_{Li} .

A numerical model was established within the set task. Numerical modelling was used to study the dynamics of spread of harmful factors from heat flow ΔP_{Fi} which stems from the fire. Boundary conditions created by additional dynamic flows at one of the portals and the outer cross-section of the intermediate air shaft inside the metro tunnel have also been examined – ΔP_{Li} = ±1, ± 10, ±100 Pa, ΔP_{Si} = ±1, ± 10, ±100 Pa. Numerical modelling time – 300 sec, 1200 sec, 2400 sec.

The effect of the location of the halted train on the dynamics of the harmful factors has been studied. In order to obtain quick and optimal results from multiparameter numerical modelling, we have introduced the 'base model concept,'(Ilias at all, Lanchava at all, 2017) which involves forming the worst possible starting and boundary conditions for the given geometric parameters of the tunnel, and obtaining the worst spatial scale and time scale for the harmful factors.

The harmful factors examined in the present study are the increase in carbon monoxide and carbon dioxide concentration levels, decrease in oxygen levels, as well as the dynamics of temperature distribution in the metro tunnel in case of a 30 MW-magnitude fire. For the correct formulation of the problem of the distribution of the temperature harmful factor, it will be necessary to consider the influence of the surrounding tunnel wall. This can be taken into account in the "base model" with the help of the technology proposed in the articles (Lancava, 1982,1985)

Detectors are located along the symmetric interface of the tunnel's cross section, at a height of Z=1.5 m from the tunnel bottom, at 100 m intervals.

Clearly, the worst possible situation applies to fires of the maximum strength required by technical regulations (30 MW), whereby the train is located at a short distance from the fire source (in our case, 602 m from the left-hand portal), and the cross section of the 10 m tall air shaft is minimal (1 m^2 in the case of our model). See Fig. 3

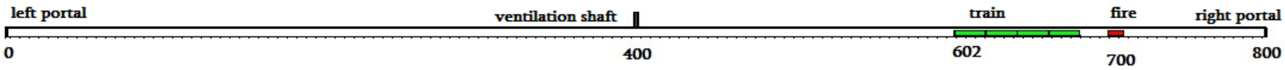

Fig.3. The Geometry data of 'base model' of metro tunnel in Pyrosim software.

Results of numerical modelling, displaying the dynamics of each harmful factor in time for the 'base model,' are shown below.

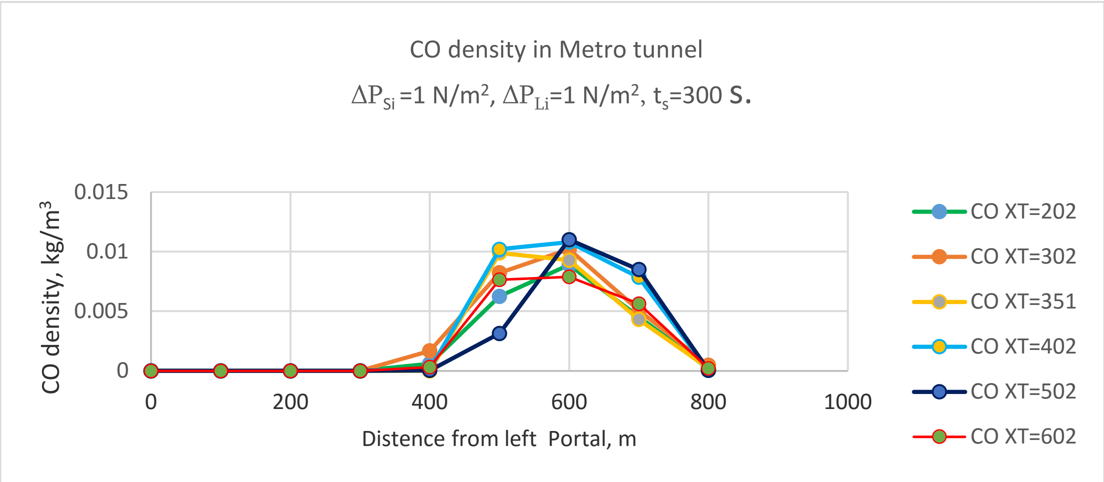

Fig. 5. Dependes of distribution of carbon monoxide concentration in the tunnel of the subway on the forced stop location of train. (HRR 30 MW, height Z = 1.5 along the tunnel, simulation time 300 seconds)

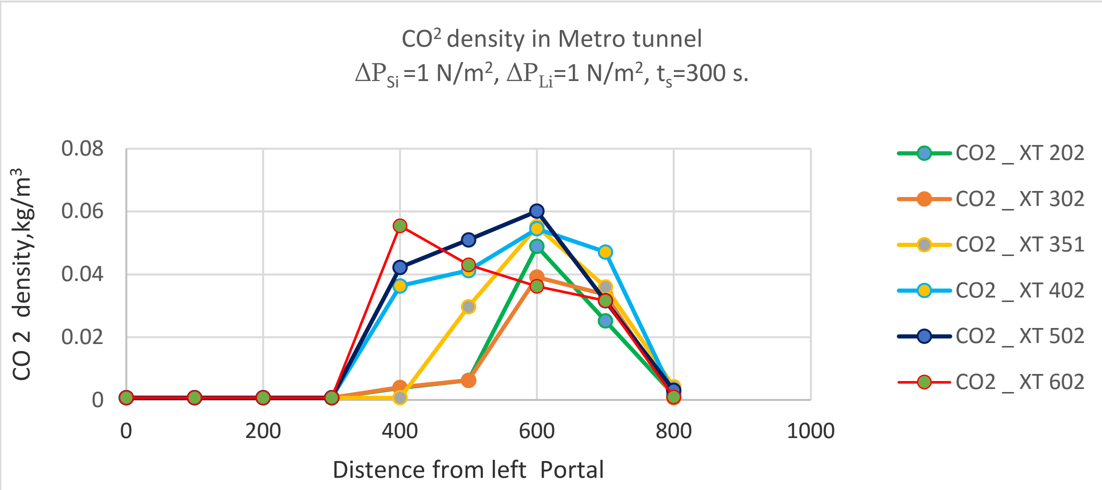

Fig. 6. Dependes of distribution of carbon dioxide concentration in the tunnel of the subway on the forced stop location of train. (HRR 30 MW, height Z = 1.5 along the tunnel, simulation time 300 seconds)

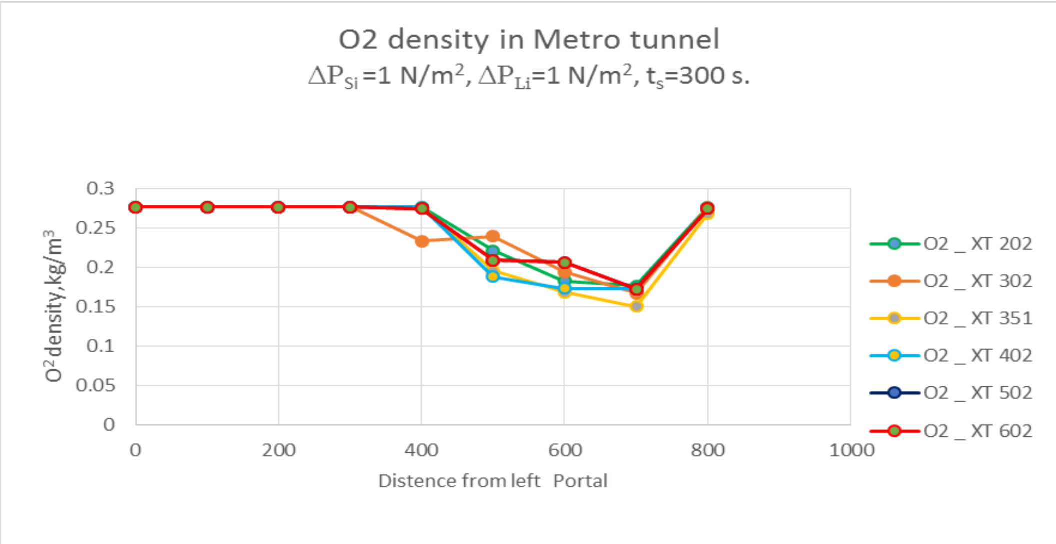

Fig. 7. Dependes of distribution of oxigen concentration in the tunnel of the subway on the forced stop location of train. (HRR 30 MW, height Z = 1.5 along the tunnel, simulation time 300 seconds)

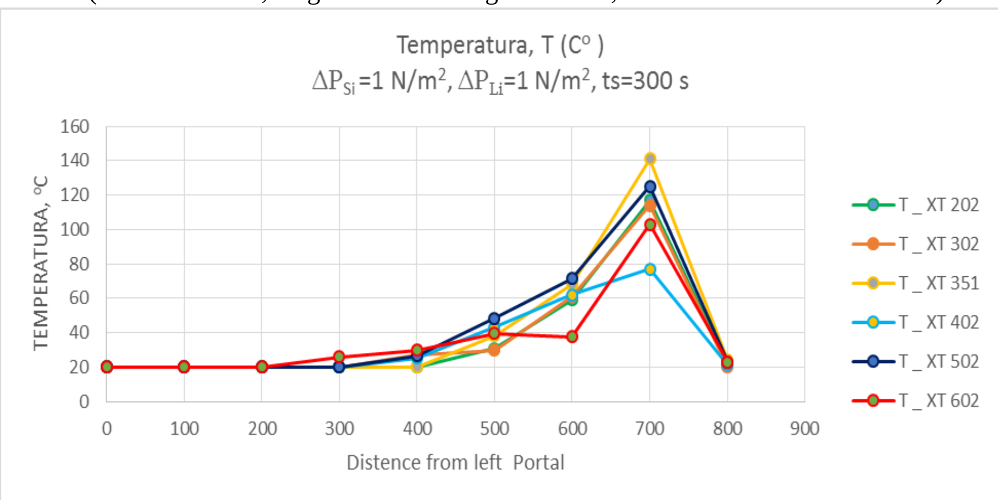

Fig.8. Dependes of distribution of Temperature in the tunnel of the subway on the forced stop location of train. (HRR 30 MW, height Z = 1.5 along the tunnel, simulation time 300 seconds)

We examine a situation where the metro tunnel ventilation system becomes disabled, which is modelled on the boundary conditions for the 'base model' – through the total minimal increase of the natural dynamic pressure on one of the portals ($\Delta P_{Li} = \pm 1$ n/m²), and the total dynamic pressure increase on the outer cross section of the air shaft ($\Delta P_{Si} = \pm 1$ n/m²)For the Basic model, the process of changing the spatial scale of the harmful factors along the tunnel was studed. time of modeling t = 300 s, 1200 s, 2400 s.The results presented on the Fig. 9-12

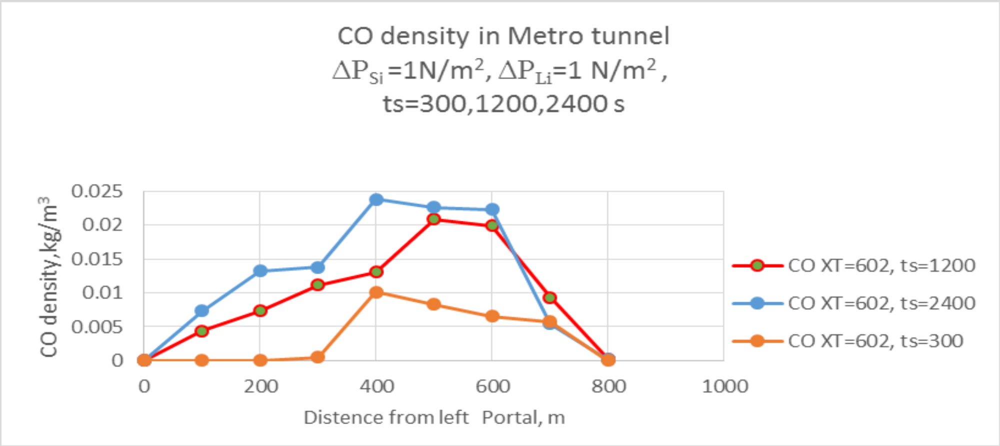

Fig.9. Dynamics of changes the spatial scale of concentration increase of carbon monoxide along the tunnel. The simulation time is ts = 300 s, 1200 s, 2400 sec.

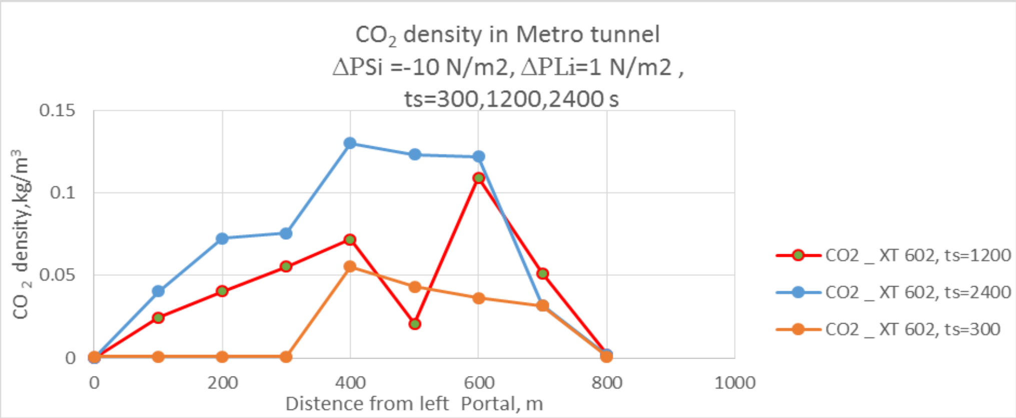

Fig. 10. Dynamics of changes the spatial scale of concentration increase of carbon dioxide along the tunnel. The simulation time is ts = 300 s, 1200 s, 2400 sec.

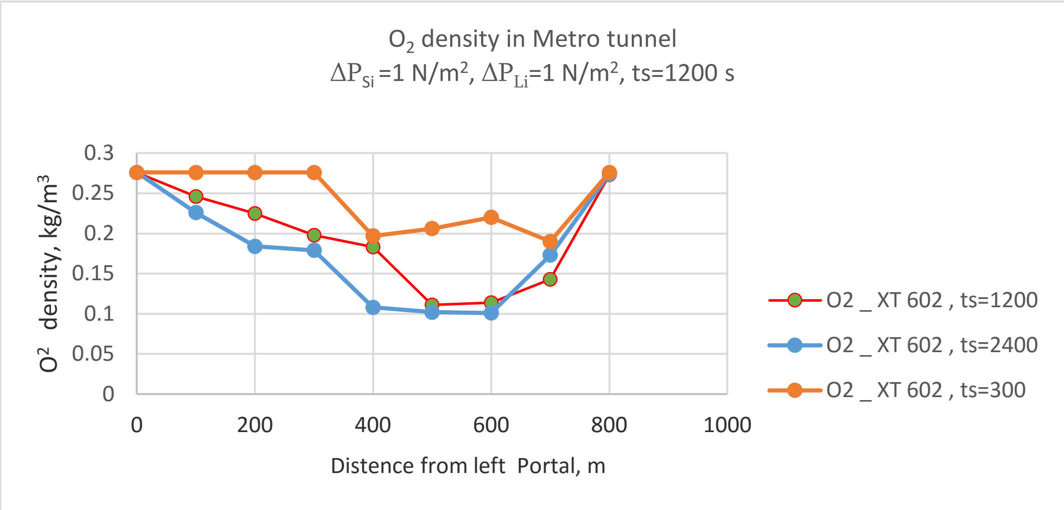

Fig. 11. Dynamics of changes the spatial scale of concentration decrease of Oxygen along the tunnel. The simulation time is ts = 300 s, 1200 s, 2400 sec.

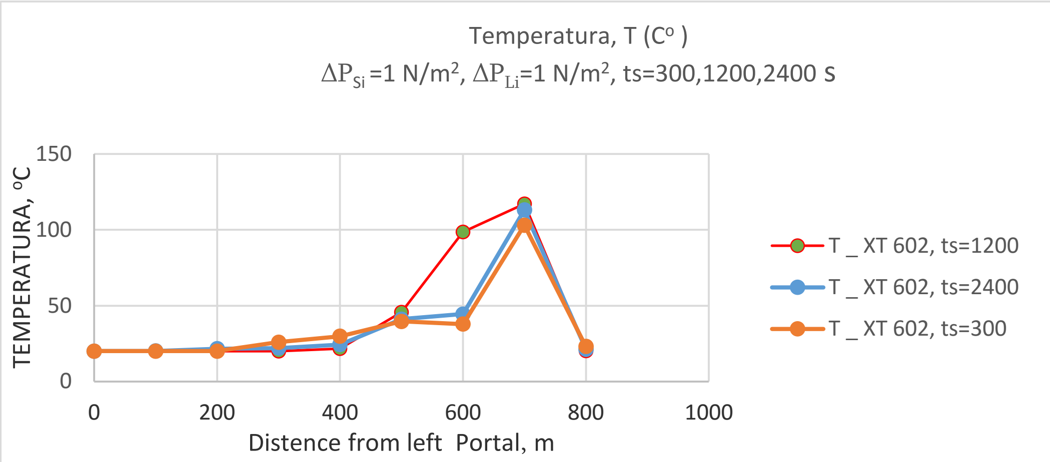

Fig.12. Dynamics of changes the spatial scale of Temperature along the tunnel. The simulation time is ts = 300 s, 1200 s, 2400 sec.

Results

Results of the numerical experiments allow us to produce a practical assessment of spatial and time distribution of the harmful factors during the realisation of various boundary conditions. The test quantity of toxic and/or asphyxiants gases is their concentration level in the tunnel space, while the thermal harmful factor is represented by the average gas temperature along the tunnel.

- The modelling of the emergency situation caused by fire inside the metro tunnel is carried out on the basis of the 'base model,' which accounts for the numerical realisation of the worst possible scenario of creation and spread of harmful factors based on the existing tunnel geometry, as well as initial and boundary conditions;
- It is shown that the dynamics of spread of harmful factors are not significantly affected by the location of the halted train, when the volumetric efficiency of the tunnel's cross section is α=0,375.;
- In case of 30 MW-magnitude fires, the spread of toxic and asphyxiant gases occurs over almost 300 m in 5 minutes, under the boundary and initial conditions that are realizd in the base model. The spatial scale of these factors is characterised by a tendency of growth.
- The danger zone of the temperature factor is quickly stabilised. Its spatial boundary is located within a distance of 100-150 m from the fire source, on both sides of the tunnel.

Acknowledgements

This work was supported by the Shota Rustaveli National Science Foundation (SRNSF) [Grant #216968].

References

Ilias N., Lanchava O., Nozadze G. Numerical modelling of fires in road tunnels with longitudinal ventilation system.*Calitatea, suppl. Supplement of Quality-Access to Success: Acces la Success; Bucharest, Vol. 18, Iss. S1*, (Jan 2017): 77-80

Lanchava O.A., (1982), Heat and mass exchange in permanent mine workings. *Journal of Mining Science* **1**(6), 87-92.

Lanchava O.A., (1985), Heat and mass exchange in newly driven mine workings. *Journal of Mining Science* **1**(5), 99-104.

Lanchava O., Ilias N., Nozadze G. Some problems for assessment of fire in road tunnels. *Calitatea, suppl. Supplement of Quality-Access to Success: Acces la Success; Bucharest***,** *Vol. 18, Iss. S1*, (Jan 2017): 69-72

Long Poon and Richard Lau – *Fire Risk in Metro Tunnels and Stations* – International Journal of Performability Engineering, Vol. 3, No. 3, July, 2007, pp. 355 – 368.

Sean Thomas McKenna and Terence Richard Hull , *The fire toxicity of polyurethane foams* - Fire Science Reviews (2016) 5:3 DOI 10.1186/s40038-016-0012.