Numerical Modeling of Ventilation Flow Distribution in Subway Tunnels with Considering of the Piston Effect

Omar LANCHAVA[1,2], Giorgi NOZADZE[1], Zaza KHOKERASHVILI[2]
[1]Gr.Tsulukidze Mining Institute, 0186, Tbilisi, Mindeli Street, 7, Georgia;
[2]Georgian Technical University, 0177, Tbilisi, Kostava Street, 77, Georgia;
E-mails: o.lanchava@yahoo.com , g_nozadze@yahoo.com, zaza196822@gmail.com

This work was supported by Shota Rustaveli National Science Foundation (SRNSF) [Grant number 216968, Project title "Prevention methods development against aerosol terrorism for ventilation of Tbilisi subway"]

Metro is the main transport artery of modern megapolis and represented complicate underground building construction. Because of its multifunctional load, leading industrial states are focused on the issue of arranging subway under modern construction standards. One of the main problem of metro construction and safe exploitation is to ensure the functioning of the ventilation system relevant to the increased safety norms. The influence of the piston effect on the dynamics of ventilation flows generated between metro stations, in the main part of scientific literature is described in the semi-empirical manner, is not characterized by high accuracy and inegatively affects on the underground design and construction works. The current level of computer technology develops the possibility of the dynamics of ventilation flows in the subway tunnels by more accuracy in terms of numerical modeling of the air flow. The paper discusses the problem of distribution of ventilation flows caused by the piston effect in metro tunnels, which give affects the determination of ventilation parameters. The task was set for the conditions of Tbilisi Metropolitan, with the following basic data: Tunnel length - 1200m; Cross section - 16 m^2, length of train 60 - 80 m; Train speed 6.0, 8.0,10.0, 12.0 m/s; Acceleration of the train – 1.0 m/s^2, the train cross section 4.00, 5.00, 6.25 m^2. The calculation was performed by the PYROSIM 2016 software. As a result of the simulation, was determined the variability of ventilation flow caused by the piston effect depending on the speed and cross section of the train and the geometry of the tunnel.

Keywords: underground, piston effect, ventilation

In this work the share of the piston effect of natural draught on the computation models and by means of same computation models are discussed. As a result of the modeling the nature of the variability of aerodynamic parameters of ventilation stream has been studied, such are: air consumption, dynamic pressure, air velocity in tunnel and velocity of back flow in space between perimeters of train and tunnel. In order to determine the mentioned aerodynamic parameters of the process we had a flow of air at one portal of the tunnel with average speed of 6.0, 8.0, 10.0, 12.0 m/s. As a result of numerical experiments, we determine the changes of dynamic pressure oscillations of the air flow along the tunnel to the front and back of the train. The base model used the following data for the Tbilisi metro: the length of the subway tunnel between two neighbor stations - L_0 = 1200 m; Train length L_{tr} = 80 m; Acceleration of train A_{tr} = 1 m/s^2.

Processing of the results, obtained by numerical modeling was performed with the appropriate values of calculations according to formulas, which were obtained from a natural experiment. In particular, the dynamic pressures difference can be calculated by formula (1) the velocity of back flow in space between cross sections of train and tunnel can be calculated by formula (2)

$$\Delta P = (0.164 V_{tr})^4, \qquad (1)$$

$$W_h = 0.84\sqrt{\Delta P}, \qquad (2)$$

and the continuity of the stream in this case has a form

$$V_{tr} S_{tr} dt = V_f S_0 dt + (S_0 - S_{tr}) W_h dt. \qquad (3)$$

Where: ΔP is the difference of dynamic pressure in front and behind of the train; V_{tr} - speed of trains in the tunnel; W_h - the velocity of air flow in space between perimeters of train and tunnel; S_{tr} = 4.00; 5.00; 6.25 - Area of the cross section of the train, m^2; V_f - air speed originated by the piston effect on the front of the train; S_0 = 16 - Tunnel cross section, m^2.

In these experiments by means of formulas (1) - (3) was realized the relevant boundary conditions. For the velocities 6.0, 8.0, 10.0, 12.0 m/s accordingly, as the boundary conditions, were used the dynamic pressures 21.6, 38.4, 60.0, and 86.4 N/m2. The train was located directly near the portal and we were analyzing the dynamic process development of air flow near the portal in front and behind the train in the part of a tunnel.

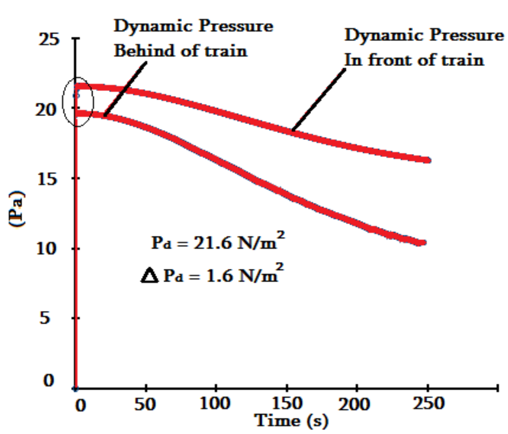

Fig. 1. Characteristics of dynamic pressure variation for the boundary condition 21.6 N/m^2

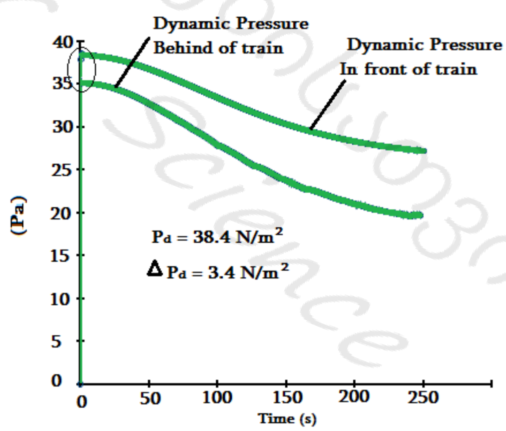

Fig. 2. Characteristics of dynamic pressure variation for the boundary condition 38.4 N/m^2

It is noteworthy, that after the equivalent dynamic pressure modes on the portal, begin the transitional processes, which need to be considered. These processes depend on the value of dynamic pressure of ventilation air flow and rate of decreasing of its intensity.

The numerical results, obtained by modeling in the case of the different boundary condition are given in figures 1, 2, 3 and 4.

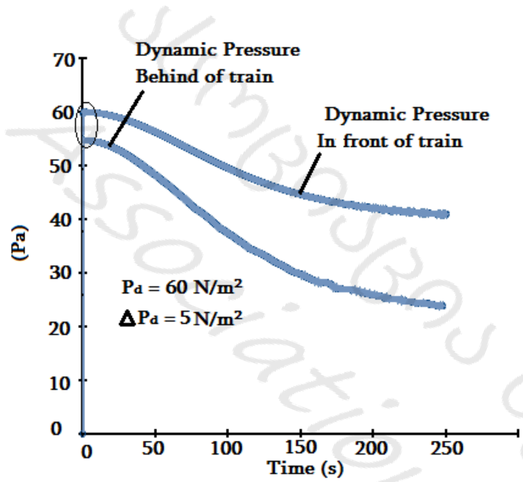

Fig. 3. Characteristics of dynamic pressure variation for the boundary condition 60.0 N/m²

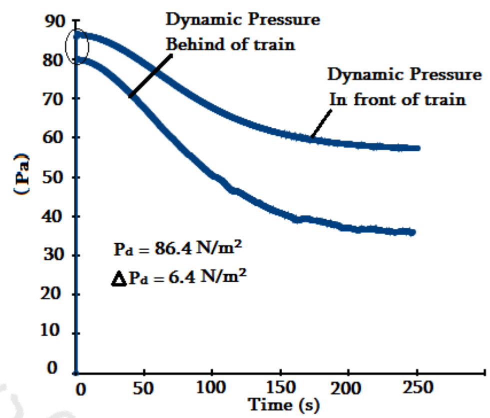

Fig. 4 Characteristics of dynamic pressure variation for the boundary condition 86.4 N/m²

As demonstrated in the results of the experimental research presented, it is possible to use the evaluation of air flows caused by the piston effect. In order to get more accuracy, it is advisable to consider the changing of pressures on the front of the train as well as behind the train for the initial phase of evolving of processes. It is necessary, as the rate of decrease of dynamic pressure is minimal in the initial phase of numerical modeling. This phase has been selected on the drawings 1-4. The results of the analysis when Str/S0 = ¼, are given in Table 1.

Table 1

Numerical analysis results

N	Boundary conditions - dynamic pressure corresponding to the speed of the train on the left portal, N/m²	Train speed in a tunnel V_{Vtr}, m/s	Pressure difference on front of the train or on the end of train ΔP_d, N/m²	The velocity of back flow in space between perimeters of train and tunnel W_h, m/s	The velocity of the flow in the tunnel that was originated by the piston effect V_f, m/s	The volume of ventilation flow that was initiated by the piston effect Q_{pi}, m³/s
1	21.6	6 .0	1.6	1.06	0.70	11.2
2	38.4	8.0	3.4	1.55	0.84	13.4
3	60.0	10.0	5.0	1.88	1.09	17.4

4	86.4	12.0	6.4	2.13	1.41	22.5

To determine the flow of air initiated by the piston effect, it is necessary to consider the tachogram of the train movement and determine the duration of the piston effect for the numerical values of the modeled velocities.

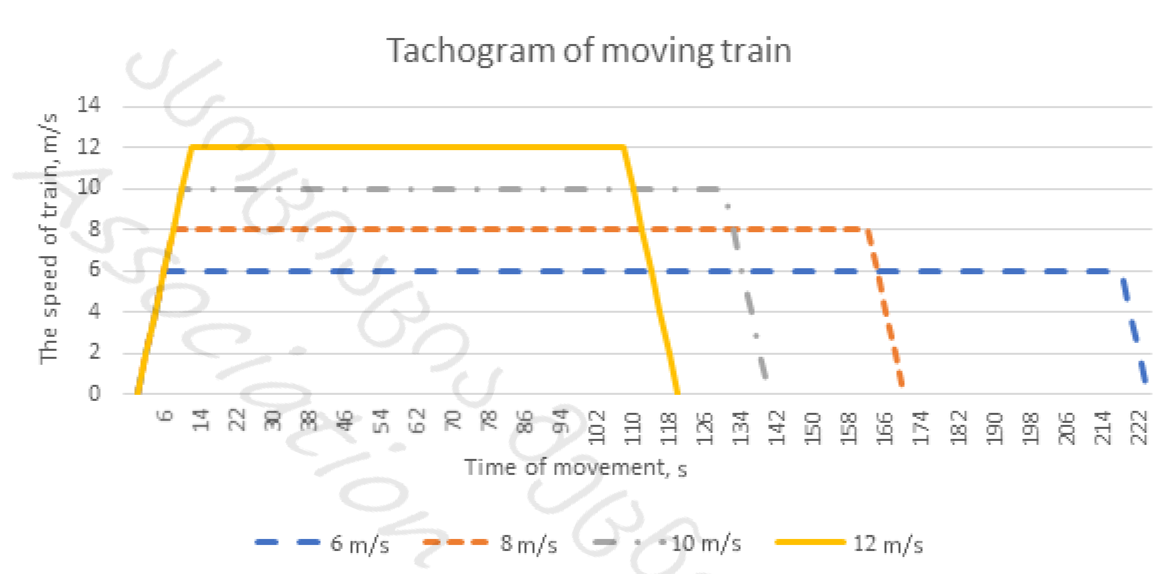

Fig. 5. The tachogram of the metro trains movement for the distance $L_0 + L_s$ = 1300 m

Train speed acceleration phase takes place in metro tunnel and the phase of the deceleration takes place in the metro station. Therefore, it is advisable to use the time (T_p) required for counting the airflow caused by the piston effect. To determine this time interval, it is necessary to use times for acceleration of the train (t_A) as well as time of constant speed during motion (t_c). Accordingly, the sum of the required times is shown in the formula

$$T_p = t_A + t_c. \qquad (4)$$

Taking into account the time (T_0) that is necessary to overcome distance between the neighboring stations the formula (4) will take the look

$$T_{pi} = T_{0i} - t_A. \qquad (5)$$

Where the index i represents a different speed of train

The air volume originated by piston effect for the different speeds can be calculated using formula

$$V_{pi} = T_{pi}Q_{pi}. \qquad (6)$$

For speeds used in the present work, according to which computer models have been executed, calculating values by formula (6) are given in Table 2.

Table 2

The duration of the piston effect in according of the speed of the moving train

Train movement speed V_{tr} , m/s	i = 6	i = 8	i = 10	i = 12
Duration of piston effect T_{pi} , c	218	162	138	108
The volume of air transported by the piston effect V_{pi} , c	2441	2170	2401	2430

Conclusions

- In the range of speeds 6-12 m/s, the variation of air flow rate, originated by the train movement has a linear character, and the volume of air intensivety, transported by the piston effect is 11.2-22.5 m3/s.
- Volume of air moved by one train in the same range of speed is practically constant and equals 2200-2400 m^3.

References

[1] S. Pan, L. Fan, J.Liu, J. Xie, Y.Sun, N. Cui, L. Zhang, B. Zheng. A Review of the Piston Effect in Subway Stations. Hindawi Publishing Corporation, Advances in Mechanical Engineering, Volume 2013, Article ID 950205, 7 pages. http://dx.doi.org/10.1155/2013/950205.

[2] H. Ingason, M. Kumm, D. Nilsson, A. Lönnermark, A. Claesson, Y.Z. Li, K. Fridolf, R. Åkerstedt, H. Nyman, T. Dittmer, R. Forsén, B. Janzon, G. Meyer, A. Bryntse, T. Carlberg, L. Newlove-Eriksson, and A. Palm. The METRO Project. Report, Mälardalen University, 2012.

[3] O.A. Lanchava. Hygroscopic heat and mass transfer in underground structures, GTU, Tbilisi, 1998, p. 272.

[4] O. Lanchava, G. Nozadze, N. Arudashvili, Z. Khokerashvili. TO DETERMINATION OF VENTILATION AIR OF THE METRO OF TBILISI BY THERMAL FACTOR. Mining Journal No 1(38), pp. 92-96, Tbilisi, 2017 (Georgian).