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Calculation of railway tunnels ventilation

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Abstract. As a result of aerodynamics calculation the total stream of air flow from piston effect of moving train and effect after movement has been determined ('effect after movement' - The residual movement of air due to the inertia of the moving air mass, when the train has already left the tunnel and the piston effect is no longer directly in effect. So residual motion adds some air stream to the main air flow) in the railway tunnel of the Marabda-Akhalkalaki. It has been determined that for the condition of those tunnels, approximately 2/3 of air flow arisen from piston effect moves in the same direction as the train moves, while the rest flows to the opposite direction into the gap the perimeters of tunnel and train. This causes air turbulence and represents component of the general aerodynamic resistance. Despite of that, all galleries of the mentioned rail highway can be aired with natural draught resulted from piston effect. For the better use of draught, caused by the piston effect ventilation gaps should be arranged in each camera and niche, on both sides of the tunnel. The area of wide section in each air hole should be 5.6 m^2. This activity will decrease aerodynamic resistance caused by the airflow in the gap of the tunnel and will guarantee air supply in the tunnel using piston effect. Thermo-physical calculation of tunnels ventilation has been performed and the work project for ventilation has been prepared. The present article sets out the results of the longest tunnel calculation. The presented results may be adjusted to shorter tunnels as well, because corresponding parameters for their conditions are milder and thus, appropriate to the norms. According to the calculation, the heat produced by the moving train can be neutralized with air flow of 4.8 m^3/s in winter and 8.4 m^3/s in summer. These air flows make sure to satisfy requirements for the maximum temperature so the temperature of airflow coming from the tunnel shall not exceed 35 ^0C for any season.

Key words: thermophysical and aerodynamic calculation; moving train's piston effect; natural traction; tunnel depression.

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1. Introduction

The tunnel ventilation project of Marabda – Akhalkalaki railway linehas been made to order by the State Projection Institute of Transport (Kiev), which is winner of bind. The present article records thermo-physical and aerodynamic calculation results of tunnel ventilations for the longest tunnel. There is the 4 one side movement tunnel of gallery construction intended on the Marabda – Akhalkalaki rail highway, technical specifications of which is represented in table 1.

Table 1. Technical data of Marabda-Akhalkalaki railway tunnels

No of tunnel	Picket	Altitude, m	Tunnels length, m	Average gradient, %	Cross section, m^2	Perimeter, m	Equivalent radius, m
3	990+27.24 1001+96.30	2150.85 2182.70	1170.0	2.722	63.12	31.78	3.97
4	1106+44.59 1109+53.51	2136.33 2135.88	308.9	0.146	63.12	31.78	3.97
5	1114+27.08 1118+52.88	2137.62 2133.85	525.6	0.717	63.12	31.78	3.97
6	1151+0.46 1156+33.094	2113.86 2105.71	533.5	1.526	63.12	31.78	3.97

Technical data of the train moving in the tunnel has been examined and included into the table 2. Particularly, cargo and passenger trains are considered as identical according to the power consumed from network, which has calculated thermalphysical ventilation with certain reserve.

Table 2.Technical data of rolling stock in Marabda-Akhalkalaki railway tunnels

Number of trains in the tunnel per day, Freight/Passenger	Carriages in one train, Pieces	Speed up/ down, kmph	Cross sectional areas: VL-10 locomotive/carriage, m^2	Full mass of loaded train, freight/ passenger, t	Trains length, m	Time of train movement in tunnel, up/down, s
23/3	24	60/25	14/13	2168/1568	426	70/169

Cameras should be arranged like chess on both sides of the tunnel at the distance of every 300 m, while in between cameras niches should be arranged similarly at the distance of every 60 m.
The geometric dimensions of the cameras and niches are presented in Table 3.

Table 3. Technical data of cameras and niches of Marabda-Akhalkalaki railway galleries

Cameras length, m	Cameras width, m	Cameras height, m	Niches length, m	Niches width, m	Niches height, m	Train movement time, up/down, s	
						Between cameras	Between niches
5.3	2.5	2.8	5.3	1.0	2.8	17.95/43.33	3.59/8.67

According to technical details, the required power for the light inside the entire tunnel is 15 kW.

There are following important issues for further consideration:

1. During the cold period of the year, when the tunnel beyond the highway is partially or completely covered with snow-drift, longitudinal scheme of ventilation is applied.

2. In all other cases we use combined scheme of ventilation, which is closes to the longitudinal – transverse scheme.

The combined scheme is arranged with ventilation windows of appropriate section set in cameras and niches, which will lead stream of air flow from piston effect inside the tunnel and the ventilation climate parameters calculated for longitudinal system will be safely protected.

Traction in these tunnels are electric therefore, no toxic substances are excreted in them. Considering the time of train's movement inside the tunnel, the volume of air necessary for people shall a priori be less than that excreted by the moving train necessary for heat offtake.

Calculation of heat excreted by the moving train should be performed for the cases when the train goes up the hill. During such a case, the part of power consumed from the network, which is not spent on increasing the potential energy of the train, shall be completely needed to overcome friction resistance of any kind that finally excretes as heat. In order to estimate the heat of train moving down the slope, the results obtained from movement of train up the slop shall be applied. The heat excreted up the hill can be determined by the formula

$$q_1 = Mn\left(N_0 L - \frac{\Delta H}{102\times 3.6}\right) \qquad (1)$$

Where q_1 is the heat excreted by the moving train, kW; M - mass of moving train, t; n - number of trains passing through the train within an hour. Mass of passenger's train is less than that of cargo train which can be seen from the table 2. We have obtained supposition about the equality of these masses, air temperature calculated with this shall have some reserve, because in fact less heat shall be transmitted and temperature increment will decrease. According to this, average value of the number of trains can be taken $n = 2{,}17$; N_0 - specific consumption of electricity, used by the train when moving up the slope in case of double traction, kW.h/(t.km); L – length of tunnel m, the tunnel in this case is calculated like one calculation area; ΔH - vertical distance between portal marks of the tunnel, m.

The amount of heat released by the rolling stock and other starting values are given in Table 4.

Table 4. The heat released by the rolling stock

Mass of rolling stock, t	Average number of trains, pieces	Average electricity consumption, kW.h/(t.km)	Vertical distance between portals altitudes, m	Total heat release, kcal/h; [kW]
2168	2.17	0.105	31.85	146098 [170]

The entire power spent on light shall be transmitted to ventilation flow in form of heat, which can be calculated by formula [1]

$$q_2 = 860 N_1 m \tag{2}$$

where N_1 is the power required for light network, kW; m - electrical loss ratio, m =1.0 .

The volume of heat excreted from light and total volume of heat together with initial dimensions are given in the table 5.

Table 5. Heat generated by illumination

Required Power, kW	Electrical loss ratio	Released heat, kcal/h [kW]	The final total heat allocated in the tunnel, kcal/h [kW]
15.0	1.0	12900 [15]	158998 [185]

In case of using one and the same scheme of ventilation according to season– calculation shall be made only for summer conditions, while in our case the calculation should be done for summer and winter seasons separately because, in winter we use longitudinal scheme of ventilation, in other seasons – longitudinal– transverse scheme.

2. Materials and methods

3.

Mass transfer potential of the air, temperature and relative humidity is calculated according to the following formulas [2]:

$$\Theta_2 = \Theta_0 - \frac{B}{A} - \left(\Theta_0 - \frac{B}{A} - \Theta_1 \right) e^{-L\sqrt{|A|}} \tag{3}$$

$$t_2 = \frac{M \pm K}{\Pi} - \left(\frac{M \pm K}{\Pi} - t_1 \right) e^{-L\chi_1} \tag{4}$$

$$\varphi_2 = \exp\left(\frac{\Theta_1}{RT_1} \right) \tag{5}$$

Where Θ_0, Θ_1, Θ_2 is the mass transfer potential of tunnel walls and ventilations respectively, J/mole. Here and below the index“0” corresponnds to tunnel walls,“1” – at the beginning of the calculation area (one of the portals), “2” – at the end of the calculation area; A, B, M, K, Π and χ_1 complexes, set in the following formulas:

$$A = \frac{K_{m\tau} P}{G c_m} \tag{6}$$

$$B = \frac{\Sigma W}{L G c_m} \tag{7}$$

$$M = \frac{1}{Gc_p}\left(K_\tau P t_0 + \frac{\Sigma Q_d}{L}\right) \quad (8)$$

$$K = \frac{L\sin\psi}{c_p}\left(\frac{K_\tau P\sigma}{G} + \frac{9.81}{L}\right) \quad (9)$$

$$\Pi = \frac{K_\tau P}{Gc_p} \quad (10)$$

$$\chi_1 = \frac{\Pi}{1 + \frac{r}{c_p} b_1 \exp\frac{\Theta_2}{RT_1}} \quad (11)$$

Where L - length of tunnel, m; e - Nepier number; t_0, t_1, t_2 - temperature of tunnel walls and ventilation flow, ^0C; R - universal constant of gas, J/(mole.deg); $K_{m\tau}$ - none – stationary mass transfer coefficient kg.mole/(J.m^2.s); P - perimeter of tunnel, m; G - mass consumption of ventilation air, kg/h; c_m - isothermal mass capacity coefficient, mole/J; ΣW - total local sources of mass in the tunnel, mole; K_τ - non-stationary heat transfer coefficient, J/(m^2.s.^0C); c_p - isobaric heat capacity coefficient, kJ/(kg.^0C); σ - geothermal gradient, ^0C/m; r - specific heat of vaporization, kJ/kg; $b_1 = \frac{1542n'}{P_A - \overline{p}}$; $n', \overline{p}$ - coefficient of approximation and partial pressure of saturated water vapor Pa, which will be taken from the source according to the temperature increment [3]; P_A - atmospheric pressure, Pa

Thermo-physical and mass-physical properties of concrete and insulation material required for thermo physical calculations are given in the table 6-9.

Table 6. Thermophysical properties of concrete

Concrete thickness, m	Density, kg/m^3	Thermal diffusivity, 10^{-3} m^2/h; [10^{-7} m^2/s]	Heat capacity, kcal/(kg.^0C); [kJ/(kg.^0C)]	Heat conductivity, kcal/(m.h.^0C); [J/(m.s.^0C)]
0.75	1900-2270	1.998 – 2.300 [5.550 – 6.389]	0.212 [0.888]	0.819-1.126 [0.952-1.309]

Table 7. Massophysical characteristics of concrete

Temperature, K	Equilibrium relative humidity, in parts of one	Isothermal mass capacity, 10^{-5} mole/J	Mass conductivity, 10^{-10} kg.mole/(J.m.s)	Thermal gradient mass conductivity, 10^{-2} J/(mole. K)
293	0.8 - 1.0	0.8 - 1.75	1.24 - 1.89	1.77 - 3.87

Table 8.Thermophysical characteristics of insulation

Insulation thickness, m	Density, kg/m^3	Thermal diffusivity, 10^{-3} m^2/h; [10^{-7} m^2/s]	Heat capacity, kcal/(kg. ^0C); [kJ/(kg. ^0C)]	Heat conductivity, kcal/(m.h. ^0C); [J/(m.s. ^0C)]
0.20	400 - 600	1.501 - 1.328 [4.169 – 3.689]	0.249 [1.043]	0.153 - 0.205 [0.178 – 0.238]

Table 9. Massophysical characteristics of insulation

Temperature, K	Equilibrium relative humidity, in parts of one	Isothermal specific mass capacity, 10^{-5} mole/J	Mass conductivity, 10^{-10} kg.mole/(J.m.s)	Thermal gradient mass conductivity, 10^{-2} J/(mole. K)
293	0.8 – 1.0	4.11 – 7.50	0.28 - 0.49	1.77 - 3.87

In order to determine none-stationary heat transfer coefficient (K_τ) and none-stationary mass transfer coefficient ($K_{m\tau}$) according to graph analysis it takes heat transfer and mass transfer should be separated from each other by using La criterion [4], generalized relationship with dimensionless temperature is presented on table 1, similar relationship persists with dimensionless mass transfer potential [5].

The none-stationary heat transfer coefficient and non-stationary mass transfer coefficient calculation formulas have been set the following way

$$K_\tau = K_1 \bar{t} \tag{12}$$

$$K_{m\tau} = K_2 \overline{\Theta} \tag{13}$$

Where K_1 is heat transfer coefficient coming from ventilation flow on atmospheric air through tunnel fortification and isolation, kJ/(kg. ^0C); $\bar{t}$ - dimensionless temperature of tunnel; K_2 - mass transfer coefficient from ventilation flow on atmospheric air through tunnel fortification and isolation, kg.mole/(J.m^2.s); $\overline{\Theta}$ - dimensionless mass transfer potential of the tunnel wall.

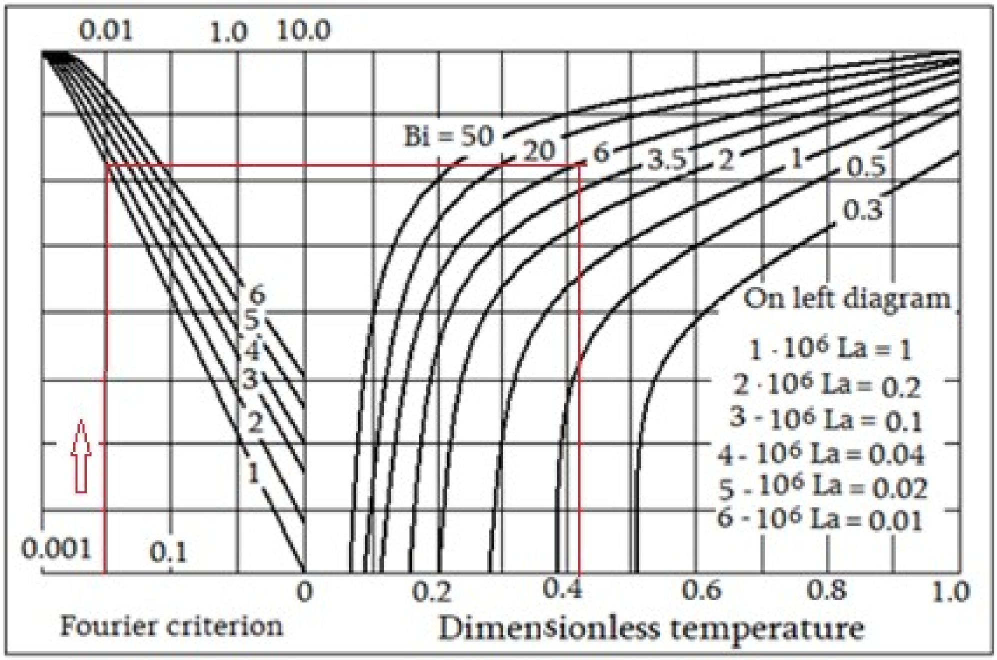

Fig. 1. Changing of dimensionless surface temperature of the tunnel $t = f(Fo, Bi, La)$.Use the nomogram as follows according to the red lines (beginning on the left diagram): $Fo = 0.01$; $10^6 La = 1.0$; $Bi = 6$; Dimensionless temperature $\bar{t} = 0.42$

Heat transfer coefficient is determined with the following formula

$$K_1 = \frac{1}{\left(\frac{1}{\alpha_1} + \frac{\delta_1}{\lambda_1} + \frac{\delta_2}{\lambda_2} + \frac{1}{\alpha_2}\right)} \tag{14}$$

Where α_1 and α_2 are thermal transfer coefficients from inside and outside of the tunnel walls, kJ/(kg.^0C); δ_1 and δ_2 - concrete and isolation thickness, m; λ_1 and λ_2 - thermo isolation conductivity coefficients of concrete and isolation, J/(m.s.^0C). in order to determine dimensionless temperature by graph analysis $Fo = \frac{a\tau}{R_0^2}$ is Furrier's criterion; $Bi = \frac{\alpha R_0}{\lambda}$ - Biot criterion; $La = \frac{\delta_\theta \alpha_m r}{\alpha}$ - new criterion; a - conductivity coefficient of temperature, m^2/h; τ - tunnel ventilation time since the moment of airing it till calculation, h; R_0 - equivalent radius of tunnels cross-section, m; δ_θ - thermal gradient coefficient of mass transfer, J/(mole.K).

Mass transfer coefficient is set in the following formula

$$K_2 = \frac{1}{\left(\frac{1}{\alpha_{m1}} + \frac{\delta_1}{\lambda_{m1}} + \frac{\delta_2}{\lambda_{m2}} + \frac{1}{\alpha_{m2}}\right)} \qquad (15)$$

Where apart from explained dimensions α_{m1} and α_{m2} are mass production coefficients from inside and outside walls of the wall, kg.mole/(J.m^2.s); λ_1 and λ_2 - mass conductivity coefficients of concrete and isolation, kg.mole/(J.m.s). In order to perform graph analysis of dimensionless potential $Fo_m = \frac{a_m \tau}{R_0^2}$ is Furrier's criterion of mass exchange; $Bi_m = \frac{\alpha_m R_0}{\lambda_m}$ - mass exchange Biot criterion; a_m - mass transfer potential conductivity, m^2/h.

3. Results and discussion

Numerical dimensions of coefficients calculated on the basis of the presented methodology have been introduced into the table 10 and 11, while the air consumption determined with thermo-physical calculation according to seasons has been included into the table 12.

Table 10.Numerical values of heat transfer K_1 and K_τ coefficients

Heat transfer coefficient in summer, kcal/(m^2.h ^0C); [J/(m.s. ^0C]	Heat transfer coefficient in winter, kcal/(m^2.h ^0C); [J/(m.s. ^0C]	Non stationary heat transfer coefficient in summer, kcal/(m^2.h ^0C); [J/(m.s. ^0C]	Non stationary heat transfer coefficient in winter, kcal/(m^2.h ^0C); [J/(m.s. ^0C]
0.565 [0.657]	0.639 [0.743]	0.509 [0.592]	0.607 [0.706]

Table 11. Numerical values of heat transfer K_2 and $K_{m\tau}$ coefficients

Mass transfer coefficient in summer, 10^{-10} kg.mole/(J.m^2.s)	Mass transfer coefficient in winter, 10^{-10} kg.mole/(J.m^2.s)	Non stationary mass transfer coefficient in summer, 10^{-10} kg.mole/(J.m^2.s)	Non stationary mass transfer coefficient in winter, 10^{-10} kg.mole/(J.m^2.s)
0.645	0.645	0.650	0.650

Table 12. Getting air consumptions that meet the requirements of construction norms and regulations

Required air consumption in winter, m^3/h [m^3/s]	Required air consumption in summer, m^3/h [m^3/s]
17420 [4.8]	30200 [8.4]

As this is visible from the table, in order to neutralize heat obtained from the moving train it is sufficient to keep the air consumptions in winter 4.8 m^3/s and– 8.4 m^3/s in summer. These air consumptions also secure satisfaction of requirements regarding maximum temperature and the temperature coming out of tunnel shall not exceed 35 ^0C throughout a year.

Securing this air consumption within the given tunnel can be arranged by the power of motion arisen by the piston effect stipulated by the moving train.

As it was mentioned in advance that approximately 2/3 of air consumption arisen by the piston effect passes in the direction of train movement, while the rest flows in the opposite direction within the gap between the perimeters of tunnel and train. This causes air turbulence and represents component of common aerodynamic resistance. Despite of that all galleries of the Marabda - Akhalkalaki rail highway can be aired with the natural draught arisen with the train piston effect.

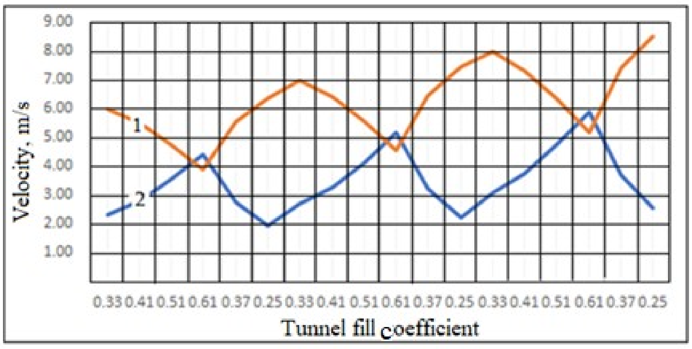

Fig. 2. The changeable character of stream speed circulated before the train and that of the flow streaming to the gap according to tunnel filling coefficient by train by calculation throughout the entire area: 1 – speed of circulated air flow in front of the train; 2- speed of flow streaming into the gap by calculating of section along the tunnel

The mentioned quality is well visible from the figure 2, composed for various tunnel filling ratio coefficients by train according to numeral experiments. The latter has been held with the help of the PyroSim software. According to ordinates, total index of the 1st and 2nd curves equals to the train speed, stimulating the circular flow speed moving in front of the train (1 curve) and the speed of flow streaming through the gap (2nd curve). The speed shown in the curve 1, actually exceeds flow, streaming into the gap 2 times, thus maintaining 2/3 of corresponding relativity.

Aerodynamic resistance of the tunnel shall be calculated by the following formula [6]

$$R = \frac{\alpha P L}{S^3} \tag{16}$$

Where R is the aerodynamic resistence of the tunnel, N.s^2/m^8; α - coefficient of aerodybaic resistence N.s^2/m^4; P - perimeter of the tunnel, m; L - length of the tunnel, m; S - cross-section area of the tunnel, m^2.
Tunnel depression is calculated with the formula

$$h = RQ^2 \tag{17}$$

where h is the tunnel depression Pa; Q - air consumption volume in the tunnel, m^3/s.
Aerodynamic characteristic of the tunnel No3 under calculation according to the aforementioned formula has been presented on the figure 3, which proves that the air consumption, within the given tunnel over the ventilation steam in case of conferring pressure equal to 100 Pascal, shall comprise 500 m^3/s.

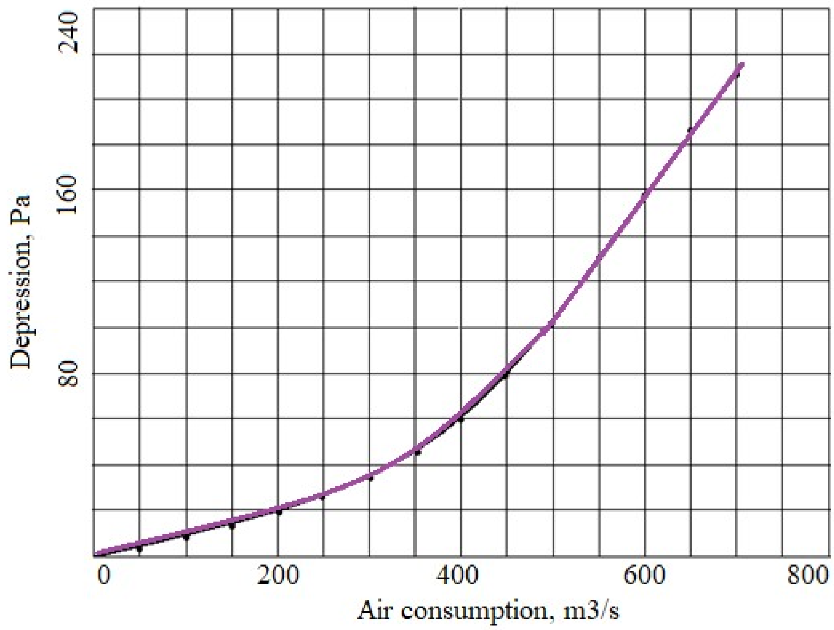

Fig. 3. Aerodynamic characteristic of the Marabda-Akhalkalaki No3 tunnel.

Calculation of depression stipulated by the moving train can be performed with the help of the following formula

$$h = \frac{\rho V^2}{2} \tag{18}$$

where h is the depression arisen by the moving train, Pa; ρ - air density, kg/m^3; average value ρ=1.2 kg/m^3; V - speed of moving train, m/s.

Another remarkable result is that the air consumption, arisen by the piston effect in diapason of 40 – 45 km/h for train speed, may vary in terms of 90-100 m^3/s, which is well visible from figure 4, composed on the basis of the results obtained from numerical modeling.

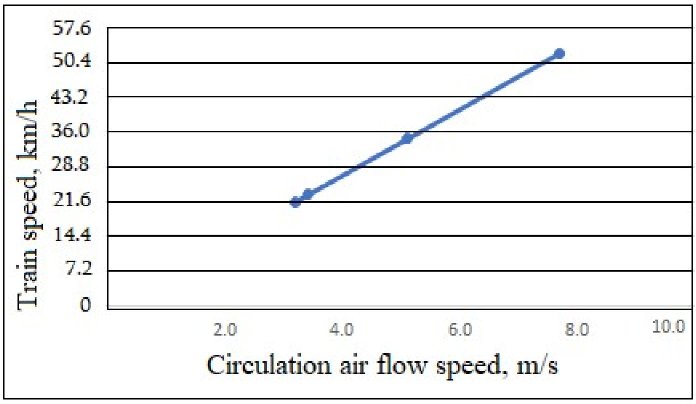

Fig. 4. Variation of air velocity caused by piston effect in according to speed moving train when tunnel fill coefficient is 0.6

Moreover, numerical experiments have been held in terms of various tunnel filling coefficients by train and various speeds. Curves exposing dynamic changes in air stream speed in front of the train as well as within the gap between perimeters of train and tunnel has been presented in the figures 5 and 6 [7].

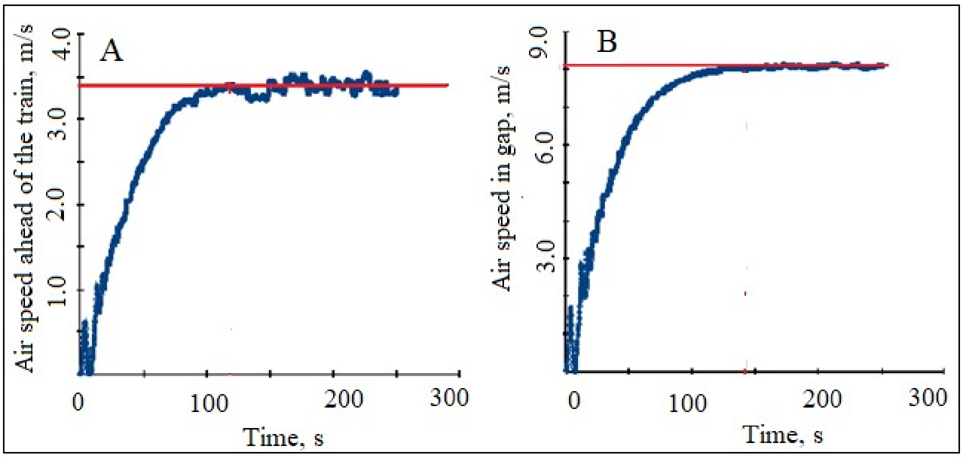

Fig. 5. Ventilation flow dynamics in front of the train (A) and between the train and the tunnel (B), when the train speed is 16.8 km/h and the tunnel fill coefficient is 0.6

Speeds of air stream flowing through gaps on the figures 5 and 6 have been determined according to cross section of the gap and not according for an entire cross section of the tunnel as expressed on the fig. 2.
The train, moving with a minimal speed in the tunnel, creates the compression zone in front of it, while behind, there arises vacuum, absorbing the new air mass and as a result the air approximately equals to the train volume is leaved the tunnel. The air flow running ahead the train shall evidently have the similar speed as the train if the train section will completely fill in the tunnel section and there will be no gap left between them. In such a case, the train moving at minimal speed pushes out the air stream equal only to the train volume. In fact, average area of train wide section is usually less than the tunnel wide section and the air normally flows back, creating aerodynamic resistance to the flow coming behind the train, decreases its speed and final stream of air consumption.

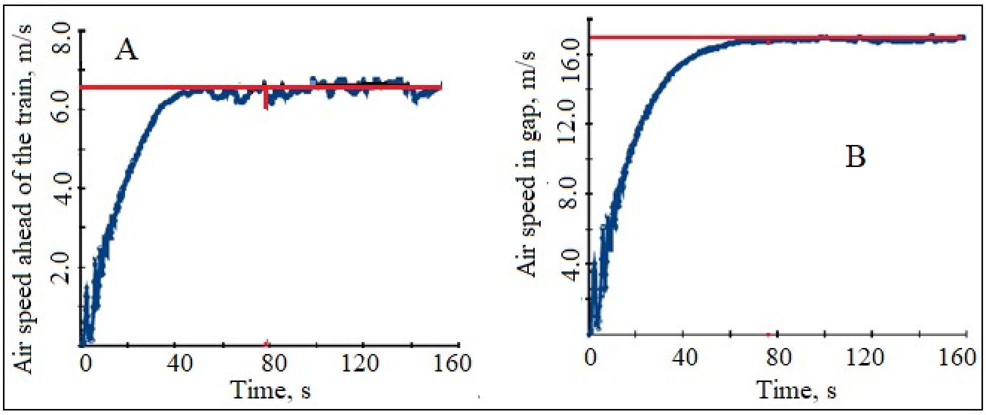

Fig. 6. Ventilation flow dynamics in front of the train (A) and between the train and the tunnel (B), when the train speed is 49.8 km/h and the tunnel fill coefficient is 0.6.

Air moving back or turning it at 180^0 can be avoided or significantly decreased if apertures are arranged near the tunnel walls, which is set at the figure 7.

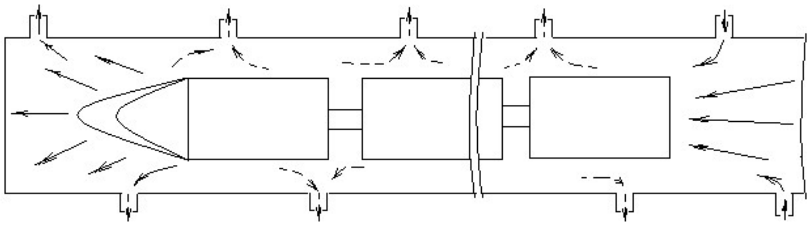

Fig. 7. Air flow stream in the tunnel, when the apertures are arranged in the walls of the tunnel.

By means of the draught of piston effect, the airflow directed to the atmosphere through apertures in walls of the tunnel. In the front apertures, at certain distance from the train, the air flow decreases, but still the stream goes out into the atmosphere, while the air is absorbed into the tunnel through apertures located behind the train, also with the decreasing values.

This significantly decreases aerodynamic resistance and a bigger volume of air stream starts moving, cause by the train depression. The more important issue is decreasing aerodynamic resistance, because the power consumed from electricity network for traction is decreased and thus, less heat is produced at the train movement.

The principle scheme presented on the figure 7 corresponds to the scheme of airing for summer period; the assignment is to select aperture sections and distances which will make the utmost effect. The depressions, calculated with the formula (18), for trains moving with 60 km/h and 25 km/h speed shall be h_{60} = 167.3 Pa and h_{25} = 28.9 Pa consequently.

h_{60} = 167.3 Pa pressure according to the speed of train and tunnel length acts for 70 seconds. During this period, the air consumption in the tunnel according to the figure 3, shall comprise 616 m^3/s, while the volume of air kept inside the tunnel within 70 seconds shall comprise 43120 m^3 in the most ideal case, i. e. unless air stream fails to go into the gap.

h_{25} = 28.9 Pa pressure works in the tunnel during 169 seconds, i. e. when train moves inside the tunnel, during which the air consumption in the tunnel according to the figure 1 shall comprise 256 m^3/s, while total air capacity preserved inside the tunnel for 169 seconds shall comprise 43392 m^3.

The situation we have obtained looks paradoxical at first glance: the train moving at less speed causes less depression inside the tunnel and carries more capacity of air in it. The thing is that the effect after movement is not taken into consideration here. By means of the effect after movement, after the tunnel is left by the train, air still keeps moving inside the tunnel at less speed. h_{25} = 28.9 Pa in case of depression the air passing through as a result of the effect after movement shall approximately comprise 80-100% of the nominal one, while h_{60} =167.3 Pa for depression it will be – 150-200%.

In this case, the duration of the effect after movement that we considered is much less, then expected in reality. This is confirmed with the results of experiment, held in the Norwegian tunnel “Fodnes” by G. Lotsberg [8]. This work refers to the air stream moving at 4.5 m/s. arisen by the ventilator, which keeps moving during 15 minutes, after turning off the ventilators, in case of truck moving, the effect after movement comprised 41 s. The speed of air stream definitely decreases through time, while decrease is caused by the aerodynamic resistance of the tunnel. Consequently, the higher the stream speed is, the less the resistance and the period of the effect after movement is longer.

Under the conditions of the h_{60} = 167.3 Pa pressure in the Marabda - Akhalkalaki tunnel, average speed of the air inside the tunnel shall be 9.8 m/s, while in case of h_{25} = 28,9 Pa pressure it will vary between - 4,1 m/s. The cross section of the

“Fodnes” tunnel is 52.00 m^2, while the cross-section area of Marabda – Akhalkalaki tunnel is - 63.12 m^2. According to formula (16), the aerodynamic resistance is inversely proportional to the section cube. Therefore, the aerodynamic resistance of the tunnel under the revision is significantly less compared to the respective dimension of the tunnel located in Norway, so the effect after movement should arrive at least within 15 minutes in terms of pressure h_{25} = 28.9 Pa, while in case of pressure h_{60} = 167.3 Pa, the effect after movement shall last before a new train arrives.

Thus, in ideal case the depression h_{25} will pass air in the tunnel approximately within 78105-86784 m^3 of diapason, while the depression h_{60} will perform in diapason 107800-129360 m^3. According to pessimistic results, in case of two trains, passing through the tunnel, the air conducted shall compose 78105+107800 = 185905 m^3.

Average number of trains moving in the tunnel during 1 hour comprises 2.17 items. Therefore, hourly consumption of air inside the tunnel shall increase with 8,5 % and will become 185905X1.085 = 201707 m^3/h.

The air consumption in the tunnel, mentioned above shall occur if respective section ventilation windows are arranged inside the walls of the tunnel according to the figure 7. Thus, the air consumption shall take place when the ventilation windows are open, i. e. during the warm season of the year.

During winter season, when ventilation windows are closed and the air flow streams through the gap between the tunnel and the train, the indicated consumption of air decreases because the air streams moving from opposite side behind the train, turbulence occurs and speed of the flow accompanying the train as well as the air consumptions are decreased. Divided air flow stream by the train can be imagined as a simple scheme, which is presented on the figure 8.

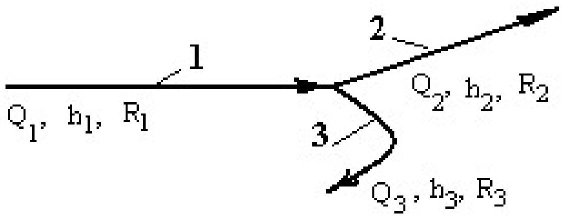

Fig. 8. Directions of airflows during train movement in the tunnel: 1 - air flow behind of the train; 2 - air flow ahead of the train; 3 - Flow in the gap

Area 1 on Figure 8 corresponds to the air flow streaming along and with the train, while the 2nd area is respective the air flow in front of the train, area 3 is the stream passing through the gap. Each of those areas are characterized the respective specifications, particularly characteristic to it, air consumption (Q), depression

(h) and aerodynamic resistance (R), indicated on the draft with corresponding indexes.
Despite the flown stream independently returning to atmosphere, from the portal on the left side described on fig. 8 or, weather joins the main stream and comes out together from the right side of the portal, as set on the figure 8, 2 and 3 branches are parallel to each other and there is the scheme given on the figure 8, which can be imagined as structural scheme, represented on the fig. 9.

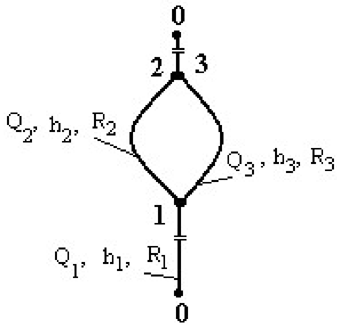

Fig. 9. Structural chart of air flows directions.

According to the basic law of parallel ventilation networks we can write

$$h_2 = h_3 \tag{19}$$

Considering the formula (17) and through simple transformations from formula (19) is obtained

$$\frac{R_2}{R_3} = \frac{Q_3^2}{Q_2^2} \tag{20}$$

From the last formula this is visible that the air capacity, passed through parallel networks are inversely proportional to their resistance, i. e. depression equity in parallel networks is reached through respective changeability of air consumption. Aerodynamic resistance of gap between the train and the tunnel is evidently unchanged despite the train's location inside the tunnel, while the aerodynamic resistance of the area 0-1 (see fig. 9) and 2-0 (or similar to 3-0) is changeable. When the equality $l_{0-1} = 0$, is preserved i. e. the train is close to the left portal according to the figure 8 while Q_3 has maximum significance, while its significance to the opposite portal is minimal.
This changeability is impossible to be determined through analysis as it requires experimental details with at least one portal with changes in aerodynamic dimension. Therefore, this dynamic assignment shall be solved through statics under the conditions when train is in geometric center of the tunnel. Aerodynamic resistance of the gap (S = 49.2 m^2; P = 45.8 m; l = 426 m) comprises 0.00052 m.s^2/m^8. by introducing the aforementioned dimensions and simple transformations from the formula (20) - (21) shall be received.

$$4.7Q_2 = 8.6Q_3 \tag{21}$$

Given relativity can most evidently refer to moving train effect after movement, when the air flow stops and extra capacity of air is captured by the stable stream, moving in coinciding direction as the train does.
Equation of air consumption balance looks similar to the fig. 9

$$1.546Q_2 = 201707 \quad (22)$$

Where Q_1 = 201707 m^3/h is maximum consumption of air in summer, when opposite stream cannot be practically arisen.
To find solution to the equation (22) by using formula (21) for the stream Q_2 moving in the same direction as train does, whereas Q_1 = 201707 m^3/h. The solution looks like the following: $1.546Q_2 = 201707$, from which $Q_2 = 130470$ m^3/h.
Thus, we can definitely determine that in winter tunnel can be supplied with almost 2/3 of summer air consumption with the help of piston effect, i. e. the air with total capacity of 130470 m^3/h. From the presented material, it is exposed that due to natural draught stipulated by the moving train, longest tunnel ventilation of Marabda – Akhalkalaki rail highway can be arranged with huge reserve considering requirements of thermo-physical calculation. For short galleries N4, N 5 and N 6 (see table 1) it is easier to obtain calculated parameters of air at the cost of the piston effect of moving train.
Air consumption stipulated by the natural draught has been included into the table 13 to the according to seasons and respective temperature increase. The natural draught stimulated on the basis of difference between air densities of air and portals has not been taken into consideration in the present work, as the tunnel has two side movement, has no artificial ventilation and factors indicated compensate themselves. If, for example, the draught arisen by the mentioned factors increases air consumption when moving up the slope, it decreases the consumption of air when moving in opposite direction and vice versa [9].

Table 13. Results of air consumption and temperature increment according to seasons

Air consumption and temperature increment in winter		Air consumption and temperature increment in summer	
Air consumption, m^3/h	Temperature increment, ^0C	Air consumption, m^3/h	Temperature increment, ^0C
130500	2.3	201700	5.1

In order to obtain better results with piston effect pressure/draught, the ventilation aperture should be arranged on all cameras and niches on both sides of the tunnel, according to the schemed set out on the figure 7. In order to simplify setting constructions, it is recommended to arrange the rest of the relatively shorter galleries with the constructions, furnished with ventilation windows.

4. Conclusions

- Aerodynamic resistance of the Marabda-Akhalkalaki railway tunnel is not big and therefore, their effective ventilation is possible at the cost of the piston effect.
- The air consumption during the winter period in the longest tunnel composes 130 500 m^3/h, while in summer it will comprise - 201 700 M^3/h. Moreover, the air consumption indicated here, also ensure meeting requirements of "construction norms and regulations" connected with temperature maximum and the air flow temperature coming out of the tunnel in any season will not exceed 35 ^0C.
- The air consumption arisen by the piston effect at the train speed diapason of 40-45 km./h. in the longest tunnel of the Marabda – Akhalkalaki Railway may vary between 90-100 m^3/s.
- About 2/3 of the air consumption caused by the piston effect in the longest tunnel of the Marabda – Akhalkalaki Railway is transferred in the direction of the train movement, while the rest flows out in opposite direction, inside the gap between the perimeters of train and tunnel. This causes air turbulence and represents the component of aerodynamic resistance. However, every gallery of the Marabda – Akhalkalaki rail highway can be aired with the natural draught originated by the piston effect of the train.
- In order to make the most of using air consumption caused by the piston effect, ventilation apertures should be arranged in every camera and niche. Area of the section of the ventilation aperture (5.6 m^2) has been determined considering the condition that the air flow streaming in front of the train does not spread beyond three ventilation apertures.
- Air should be absorbed in the tunnel through the fourth aperture behind the train and from the rest of the apertures, while the air shall be streamed within of the tunnel in the first three apertures located behind the train.

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