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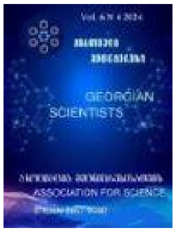

Scenarios of fire behavior using physical models of tunnels with different inclinations

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Abstract

Critical velocity remains one of the most important design parameters in the theory and practice of emergency ventilation of road tunnels. It should be noted that basing practice only on this value can lead to serious error. Therefore, it is necessary to take into account other important parameters of a particular tunnel and to develop in advance a clear algorithm of actions to manage emergencies. In this paper, numerical and physical models are used to investigate the scenarios of fire development of different strengths. The nature of the expected aerodynamic resistance in the tunnel caused by fire is analyzed. In particular, the reduction of ventilation velocity caused by the throttle effect and the algebraic summation of flows are distinguished from each other. Fires are simulated in a stainless metal sheet tunnel model in a laboratory setting, taking into account the critical Froude number, and the nature of the backlayering length variation depending on the tunnel slope is illustrated. The paper shows that the fire not only practically "reduces" the tunnel cross-section, but also causes additional traction due to the change in the density of the air mixture, which acts against the fan in the case of downward ventilation. It is also demonstrated that in inclined tunnels, in case of deactivated ventilation, when only natural traction acts during the fire, it is possible to reliably determine the numerical value of the critical ventilation velocity.

Keywords: tunnel ventilation; underground fire; critical velocity; backlayering length; Freud's Criterion.

1. Introduction

Under the new rules and guidelines of the European Transport Commission of December 2021, about 50 road tunnels built and commissioned on the Georgian highway in the last three years belong to the Trans-European Network [1]. As a result, a new transportation corridor was created: involving the Baltic, Black and Aegean Seas. According to the design solutions of these tunnels and considering their operating conditions, one of the main expected threats is fire. Heat, smoke and toxic combustion products can spread from the fire source through the tunnel in both directions, causing injuries to people of varying severity. In any case, underground fires cause serious consequences and are an obstacle to evacuation and saving lives. This significantly complicates the working conditions of rescuers and firefighters, and disables an important element of the transportation infrastructure - the tunnel - for a long time. On this basis, the study of scenarios of fire development in highway tunnels and the development of methods to prevent the expected danger are of great importance to ensure their safe operation.

Unlike open areas, there is not always enough oxygen in a tunnel and therefore two types of fire occur: a) Fuel Controlled Fire (FCF) and b) Ventilation Controlled Fire (VCF). In the case of FCF, there is a lot of air and the power of the fire (amount of heat, smoke, toxic combustion compounds) is determined by the amount of fuel. In such fire conditions, due to the large amount of air, the concentration of combustion products in the air is relatively low. In the case of VCF, the fire power is determined by the air flow rate because the amount of fuel is large at this time. In this case, the concentration of combustion products is high and an explosive concentration of volatile substances may be created.

The following strong road tunnel fires are worth mentioning: the fire that occurred in the Japanese tunnel “Nihodzaka” in 1979 as a result of collision of vehicles; the fire raged for 4 days and nights and was localized only after all kinds of combustible materials were exhausted in the tunnel; In 1982 in the “Caldecott” tunnel (USA) as a result of an accident due to the fault of a drunk driver, a strong fire occurred, and 7 people died; In 1982, a fire near the city of Beaun in France killed 53 people, including 44 children; In the France-Italy “Mont Blanc” tunnel in 1999, a fire broke out in the engine of a car, the driver was unable to extinguish it, left the car and walked towards Italy; Before the tunnel management closed the tunnel, all cars entering from the French side were in the fire zone and no one survived, while all cars entering from the Italian side survived. Toxic gases spread from the portal located on the Italian side towards France at a speed of 1 m/s, the fire raged for 53 hours, after extinguishing the fire for 5 days, hot gases escaped by natural draught from the tunnel. 40 people died, including 1 firefighter. This was the 18th and worst fire since 1965 for this tunnel; The fire that occurred in the Tauern Tunnel in Austria in 1999, caused by a collision of vehicles, lasted 15 hours; The fire in the Gotthard Tunnel in Switzerland in 2001, caused by a collision of vehicles, lasted 20 hours [2, 3].

The fires that occurred in the late 20th and early 21st century received a lot of public attention as a result of the journalistic activities. In addition to the fires listed above, fires that occurred in other road tunnels also had a great impact. In particular, a large fire occurred in the Baku Subway in 1995 and killed more than 200 people; In 2003, an arson attack in South Korea's Daegu Metro killed nearly 200 people; An incident in Kaprun, Austria, in 2000, where a fire in a cable car killed 151 people; the same fire killed the driver of an oncoming train and 3 people waiting for transportation at the upper portal.

A sign of such great attention is the establishment of a group of international experts at the UN European Commission, headed by the Ministers of Transport of the EU member states. The said group prepared and periodically issued relevant documents, some of which are cited in the verified sources [4-11].

In our previous papers [12] we mentioned and will repeat here that the said group of experts made certain mistakes. In particular, in paragraph 8 of their report on the fire in the tunnel of the Gotthard highway in Switzerland they noted that the emergency ventilation of the tunnel worked effectively, and in the next paragraph it is noted that people died as a result of inhalation of combustion products. Let us quote the above-mentioned provisions from the above source [5]: “8. The rescue team had arrived on the scene of the accident within 2 minutes. The smoke was contained in a two-kilometre stretch of the tunnel. All the tunnel facilities such as emergency lighting, ventilation, traffic management, etc. functioned as planned and efficiently. 9. The 11 victims were found 1 to 2 kilometers away from the fire. None of them had injuries. All died from toxic smoke inhalation. Some of the victims were found dead at the wheel of their vehicle...”

After examining the aforementioned mistakes, we brought the fundamental idea of researching large fires into the scientific circulation: that, in the event of a fire, the ventilation flow can no longer be influenced by fan operation after a specific amount of time, regardless the type of effect of the high temperature affect, whether an increase in dynamic pressure caused by the fire, or a decrease in air density, or both. In this case, the ventilation system collapses, which is a process of emergence and propagation of a dominant dynamic pressure commensurate with the depression of the tunnel ventilation system as a result of a strong and rapidly developing fire. It should be noted that the dynamic pressure caused by the fire is algebraically summarized with the pressure developed by the fan [13-15].

The result obtained from FDS modeling is very close to the collapse given in [16], where it is specifically noted that the fire tends to resist the propagation of the ventilation jet: the larger the fire, the greater the resistance. It is clearly demonstrated that more and more jet fans are required to remove the combustion products from the tunnel as the fire increases. It is noted in [17] that the According to the results of our numerical modeling, it can be noted that the change in the ventilation flow rate in case of fire is an effect due to both the increase in aerodynamic resistance and the influence of algebraic summation of the flows (Fig. 1.). This effect may also extend to the case of collapse.

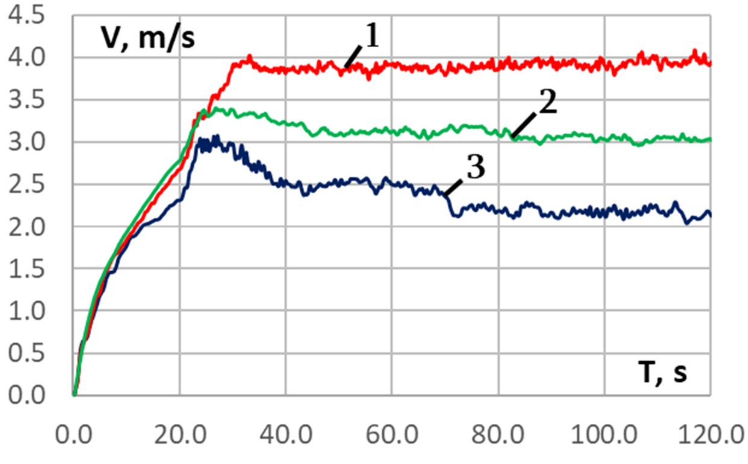

Fig. 1. Variability of the average velocity of the ventilation flow for a 50 MW fire in the tunnels of different inclinations: 1 – Inclination 6 % (ascending flow); 2 - Inclination 0 %; 3 - Inclination 6 % (descending flow).

Figure 1 shows the results of variability of the ventilation flow average velocity for a 50 MW fire. As Figure 1 shows, in case of a zero-tunnel inclination, it can be seen that the fire is a resistance to the ventilation flow (curve 2). Jet ventilation started at 0.00 s and the ventilation flow reached a velocity of about 3.4 m/s. A 50 MW fire activated in the central part of the tunnel at 20 s reduces the air velocity by 0.4 m/s because of the throttling effect. In this case, the traction caused by the fire is zero. In case of a descending ventilation flow (curve 3), the ventilation flow has a positive direction, and the fire still acts as a resistance to ventilation and in this case too, reduces the air velocity by about 0.4 m/s, while the remaining speed reduction by about 1.4 m/s is the algebraic sum of the negative direction flow induced by fire and the ventilation flow of a positive direction. In case of an ascending ventilation flow (curve 1), the algebraic sum of the ventilation flow and the flow induced by fire increases the total flow by approximately 1.3 m/s, as both flows have the same (negative) direction. In this case too, fire is an aerodynamic resistance to the ventilation flow and the total velocity is reduced by the relevant value, by approximately 0.4-0.5 m/s [18].

Thus, the fire not only practically “reduces” the cross-section of the tunnel, but also due to the change in the density of the air mixture causes additional resistance, which in the case of downward ventilation acts against the fan.

Since the fire may occur in a train car or other vehicle, it is necessary to know the peculiarities of fire development for this case, which is closer to an apartment fire (AF) than to a tunnel fire (TF).

Note that tunnel fires and apartment fires differ from each other in at least four ways:

1. Regardless of the method of tunnel ventilation: natural or mechanical draft, combustion in the vehicle itself is always dictated by the natural effect of the air entering the openings. In this case, the ventilation factor is determined by the geometry of the opening (window, door) from which the air enters and is calculated by the formula $A_0\sqrt{h_0}$, ($m^{5/2}$) where A_0 is the area of the opening cross-section and h_0 – is the height of the opening. As it is known, the TF parameters, in addition to geometry, depend on the tunnel slope, properties of the surrounding massif (which itself may be combustible or emit combustible gases), weather conditions in the vicinity of the portals, the topology of the portals, etc. An apartment fire is almost always controlled by ventilation and is consequently characterized by explosive combustion products.

2. Peak velocity of an AF is reached faster than with TFs. In general, the reaching peak velocity in decreasing time order is as follows: tunnel, apartment, and open fire. It is not difficult to see that AFs have greater possibility of explosion than TFs because the latter can be fuel-adjusted as well.

3. A TF is characterized by backlayering, while AFs are characterized by back-extrusion, which is an abrupt change in the ventilation mode in case of ventilation-controlled fires, increasing oxygen with air and increasing fire.

4. Stratification of smoke and combustion products. In case of AF, combustion products are at the top and cold air is at the bottom. A similar stratification is characteristic of the cross ventilation system

in the TF, which is relatively rarely used due to its high cost. It should be noted that we propose a flexible ventilation system, which promotes the formation of bifurcation (split) flows and can be used at the stages of evacuation and firefighting even with cheap longitudinal ventilation system. The boundary between bifurcation flows in this system is easily eliminated in long tunnels and especially in case of backlayering. The buoyancy of one gas to another is represented by a dimensionless parameter, the Richardson number (Ri), which shows the mass exchange between the layers and in this is different from the Froude number (Fr), which shows the common shape of the layer in the ventilation flow. The results of numerical analysis of ventilation-controlled tunnel fires are given in works [19-24].

2. Critical velocity analysis

Critical velocity and length of backlayering are important technological parameters that define and determine the means of evacuation and the methods of extinguishing the fire. Critical velocity is defined as the minimum longitudinal ventilation velocity that excludes the formation of smoke backlayering, i.e. this velocity is a control indicator of the propagation of combustion products. The dependence of critical velocity on heat release in horizontal tunnels has been extensively studied, whereas inclined tunnels have received less attention due to their complexity.

All along backlayering, smoke spreads against the ventilation flow. This is particularly intense if the ventilation flow is moving from a high position to a low position and the fire origin is at a low position. The backlayering length is a more important indicator of the fire stage, and the use of critical velocity is more characteristic of evacuation.

The numerical value of the critical velocity u_c in an inclined tunnel can be calculated by using the critical velocity $u_{c(0)}$ for a horizontal tunnel by the following equation [25]

$$u_c = K_g u_{c(0)} \qquad (1)$$

where K_g is a gradient-factor – i.e. the correction factor based on tunnel slope used for inclined tunnels in the event of a fire.

NFPA 502 provides a correction factor equation for inclined tunnels

$$K_g = 1 + 0.0374 s^{0.8} \qquad (2)$$

where s is the tunnel inclination, %. The slope is determined by the ratio of the height of the tunnel's upper portal from the horizon to the horizontal length of the tunnel. If the angle of inclination of the tunnel is θ, the slope of the tunnel will be $tg\theta$. s in formula (2) is the slope expressed in percent, i.e. $s = 100 x tg\theta$ s.

The critical velocity can be calculated by the formula

$$u_c = k\left(\frac{g\dot{Q}_c H}{\rho_0 c_p T A}\right)^{1/3} \qquad (3)$$

where u_c is the critical velocity, m/s; k is the constant of proportionality; g is the acceleration of a free falling body, m/s^2; $\dot{Q}_c$ is the convective heat released as a result of fire, kW; H is the tunnel height, m; ρ_0 is the density of ambient air, kg/m^3; c_p is the specific heat capacity of air, kJ/(kg.K); T is the average smoke temperature, K; A is the ross-sectional area of the tunnel, m^2.

The proportionality constant is determined by the formula

$$k = \mathrm{Fr}_c^{-\frac{1}{3}} \tag{4}$$

where Fr_c is the critical Froude number, determined by the formula

$$Fr_c = \frac{\Delta\rho g H}{\rho_0 u_c^2} \tag{5}$$

where in addition to the explained values, $\Delta\rho$ is the difference of densities of ambient air and smoke, kg/m^3.

The average smoke temperature is calculated by the formula

$$T = T_0 + \frac{\dot{Q}_c}{\rho_0 c_p A u_c} \tag{6}$$

where in addition to the explained values, T_0 is the ambient air temperature, K.

It should be noted that to determine the critical velocity u_c by formula (3), it is necessary to know the proportionality constant k and the average smoke temperature T, while the formulas for their calculation (4)-(6) contain the sought value u_c. To overcome this, they introduced a constant, the critical Froude number, equal to 4.5, which, as we will see below, is not a solution to the problem.

The critical velocity was first related to the Froude criterion by Thomas [26], who noted that the nature of the flow of combustion products and air mixture in a tunnel depends on the ratio between the buoyancy of the smoke and the inertia forces of the tunnel ventilation current, which is expressed by the Froude criterion, and for small-scale alcohol flames, he introduced the numerical value equal to criterion critical 1, which also means that k =1 and does not mean that $T \approx T_0$.

The work of Lee et al. [27] investigated a fire caused by a wooden barrier of 0.3*0.3*10 m in a test tube, and it was observed that the aerodynamic drag at the fire source increased by a factor of 6 for the ventilation inflow, and also on both sides of the fire by a factor of about 1.5. Backlayering was observed when the throttled ventilation flow velocity at the fire source was 0.6 m/s, corresponding to a Froude criterion number of ~7.

Danziger and Kennedy [28], without having studied the processes thoroughly, expected, like the Reynolds number, that the Froude criterion would also have a critical numerical value, introducing a critical numerical value of 4.5, presumably according to the work by Lee et al. what has been the subject of discussion by many authors over the years regarding critical velocity and backlayering distance. This assumption simplifies the issue because in this case, according to formula (4), the coefficient $k = 0.606$, but this is not correct.

Kennedy's presentation “Critical velocity: past, present and future”, which he made in London in 1996 at the seminar “Smoke and critical velocity in tunnels” [29] gives similar results.

The variation of the critical velocity by Froude number when the temperature of the ventilation flow varies between 573-1373 K is shown in Fig. 2.

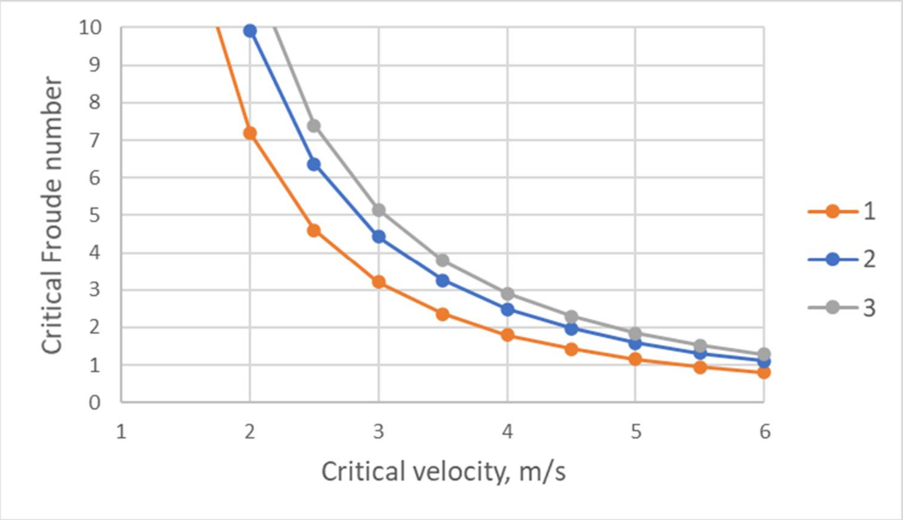

Fig. 2. Variation of the critical Froude number depending on the critical velocity at tunnel height of 6 m, ambient air temperature 293 K, average smoke temperature (K): 1 – 573; 2 – 903; 3 – 1373.

From the figure, it can be seen that the numerical value of the critical velocity varies between 2.5-3.2 m/s provided $\mathrm{Fr}_c = 4.5$. In fact, the range of variation of the critical velocity is wider, and in this regard, it can be noted that the critical Froude number is not equal to 4.5 what should be considered in the design of emergency ventilation projects. Although equation $\mathrm{Fr}_c = 4.5$ is less accurate in describing tunnel fires, there arises a distinct question about the use of the Froude criterion in laboratory experiments what will be discussed below.

3. Physical modeling methodology and obtained results

Froude criterion modeling strategy is widely used in fire experiments. Its essence is that the Froude number characterizing the forces of inertia and buoyancy will be directly preserved in the experiment. In the case of Froude modeling, the temperature field is the same, and the scale of heat release and ventilation rate are characterized geometrically by the following formulas

$$\frac{Q_m}{Q_n} = \left(\frac{\ell_m}{\ell_n}\right)^{2.5} \quad (7)$$

$$\frac{u_m}{u_n} = \left(\frac{\ell_m}{\ell_n}\right)^{0.5} \quad (8)$$

where Q_m is the value of convective heat release of the model, KW; Q_n is the value of convective heat release in nature, KW; ℓ_m is the tunnel length on the model, m;ℓ_n is the tunnel length in nature, m; u_m is the air velocity on the model, m/s; u_n is the air velocity in nature, m/s;

In the physical model, the length of the tunnel was 12 m, the cross-section was 0.467 m^2, the width was 0.85 m, the height was 0.55 m, and the width to height ratio was 1.54.

For physical modeling we choose a linear scale $M_l = {}^{l_m}/_{l_n} = {}^{W_m}/_{W_n} = {}^{H_m}/_{H_n} = 0.1$. The other scales of modeling will be: scale of heat release index according to formula (7): $M_Q = 0.00316$; Scale of ventilation rate according to formula (8): $M_u = 0.316$.

The tunnel model is made of 2 mm thick stainless steel sheets. Air was supplied through a duct fan. The fire source was porous burners with a surface area of 130X50 mm and 340X60 mm. The fire source surface was at the tunnel floor level. Natural gas was used for heating, the flow rate of which was measured with an accuracy of 1%. The heat release index for the model was calculated using the gas flow rate. The air flow rate in the tunnel was measured with a flow meter with an accuracy of 1%. The air velocity was not measured, but was calculated from the air flow rate and the tunnel cross section.

The tunnel cross-section occupancy factor with vehicles $\alpha = 8\,\%$ assuming that there is 1 car of 2014 Nissan Patrol in the cross-sectional area at the source of the fire. The air flow and variation of velocities on the model and in nature are given in Table 1.

Table 1. Air flow and variation of velocities on the model and in nature

Air flow, m^3/h	Air velocity of model, m/s	Air velocity in nature, m/s
20 -150	0.185 – 1.389	0.59 – 4.4

Backlayering was determined on the model by temperature change using stainless steel $k-type$ thermocouples. In the model tunnel, thermocouples were installed 20 mm below the ceiling along the entire length of both ascending and descending flows. From the center of the tunnel, 40 thermocouples each were installed on both sides of a 2-2 m long section (for a total length of 4 m) so that the distance between their axes was 0.1 m. In the remaining length of the model tunnel, thermocouples were also installed with a distance of 0.2 m between their axes.

Fig. 3. Tunnel model with thermocouples and measuring instruments.

The monitoring system consisted of a central data collection central module DT85 manufactured by Datataker and four types of sensors connected to it (two types of thermocouples, an air flow meter, and a gas mass flow controller/counter). Thus, the fuel gas flow rate was regulated by means of a central measuring device. Registration and further processing of information on the speed and temperature of the air in the tunnel was also carried out through the central module. Temperature readings were taken from thermocouples when the temperature on the model exceeded the ambient temperature by at least 5 degrees. The tunnel model in horizontal position and the measuring instruments are shown in Fig. 3. The inclination was provided by special telpher and model retention devices.

The convenience of Froude numerical simulation is especially emphasized in the case of comparison of model and natural values of heat release rate. Modeling a 5000 kW fire using the Froude number at the appropriate scale of M_Q = 0.00316 mentioned above requires only 15.8 kW of power on the model, which provides a high standard of fire safety in the laboratory.

The fire development scenario in a horizontal tunnel is shown in Fig. 4. The fire source, i.e. the Nissan Patrol car are placed in the center of the tunnel so that its point of symmetry on the tunnel model coincides with the 648 cm mark. According to the Figure, the movement of fresh air is from left to right.

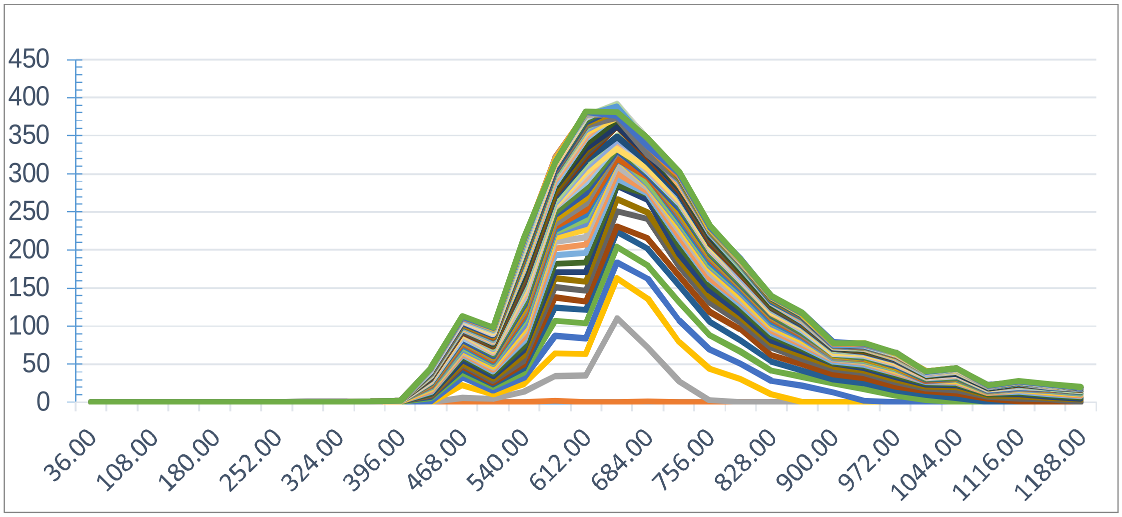

Fig. 4. Change of air temperature during the fire according to thermocouple data on a physical model of a horizontal tunnel (℃):

Temperature change curves are plotted by the “data-taker” at all points simultaneously at 1 s intervals. The abscissa axis shows the distance of the thermocouple from the left portal of the model in centimeters, which is calculated by multiplying the proper dimensions of the tunnel in nature by the linear scale of the modeling (M_l = 0.1); Ventilation flow is from the left.

From the fire source in the left part of the tunnel, backlayering is observed, i.e. the case when toxic combustion products spread in fresh air opposite to the movement of the latter. From the fire source in the left part of the tunnel, backlayering is observed, i.e. the case when toxic combustion products spread in fresh air opposite to the movement of the latter. Under these conditions, the ventilation flow velocity is less than the critical value; the velocity on the model is about 0.25 m/s. The distance from the source of the fire to the point reached by the temperature disturbance is the length of backlayering. According to the results presented in Fig. 4, the length of backlayering on the tunnel model is 288 cm, which corresponds to 28.8 m in nature - in the real tunnel, according to M_l = 0.1 linear scale of the modeling.

Consider the conditions given in Fig. 4 for the most complicated case of downward ventilation on tunnel models of different inclinations. For all considered examples, the ventilation flow rate is less than the critical velocity and the idea of critical velocity is valid. The fire source, a Nissan Patrol car, in this case too, was placed in the center of the tunnel so that its point of symmetry on the tunnel model coincides with the 648 cm mark, corresponding to the length of the tunnel in natural conditions of 64.8 m.

The inclination of the tunnel model was adjusted by raising and lowering the left gantry of the model with a special device so that the right portal remained almost stationary. After setting it on a fixed slope to simulate downward ventilation flow, as can be easily seen, the movement of fresh air was from left to right, while the combustion products moved in the opposite direction due to buoyancy. The downward ventilation fire scenario for a tunnel model with a 3% slope is shown in Fig. 5.

As Fig. 5 shows, the peak air temperature of 290℃ coincides with the fire source. The ventilation flow velocity on the model is increased to 0.4 m/s, after algebraical summation of the mechanical (fan-driven) and thermal ventilation flows, the length of backlayering on the model is 252 cm, which is about 25 m for a real tunnel.

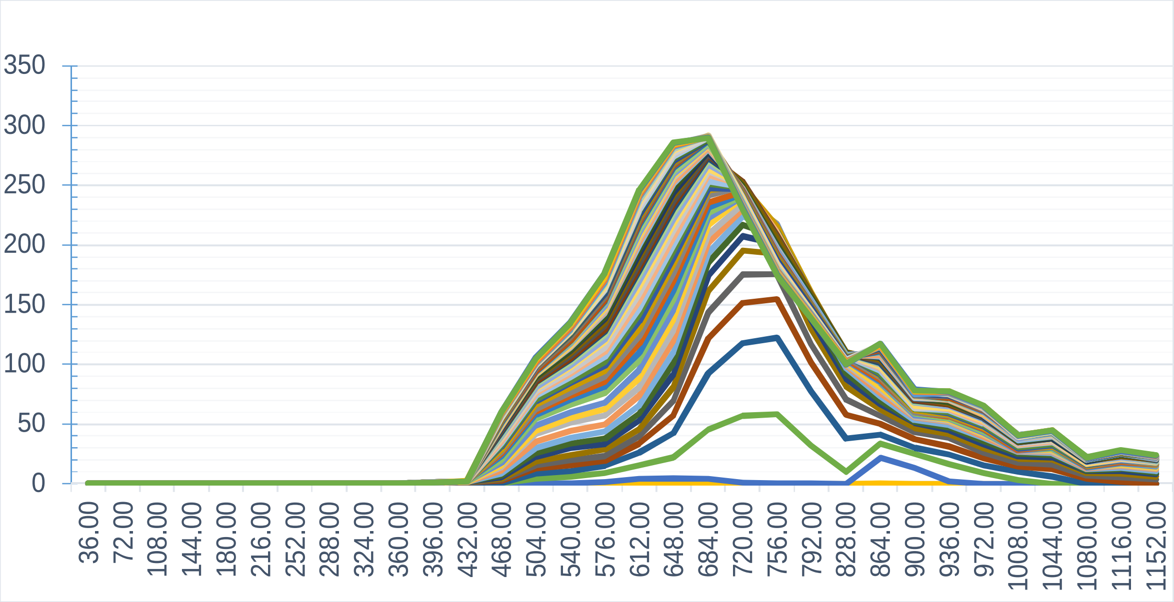

Fig. 5. Fire development scenario on downward ventilation flow:
Tunnel slope: 3%; Combustion products in this case are also directed to the left, and the direction of the ventilation flow is opposite; Air temperature change is given by thermocouple data (℃); backlayering length is reduced compared to the previous cases.

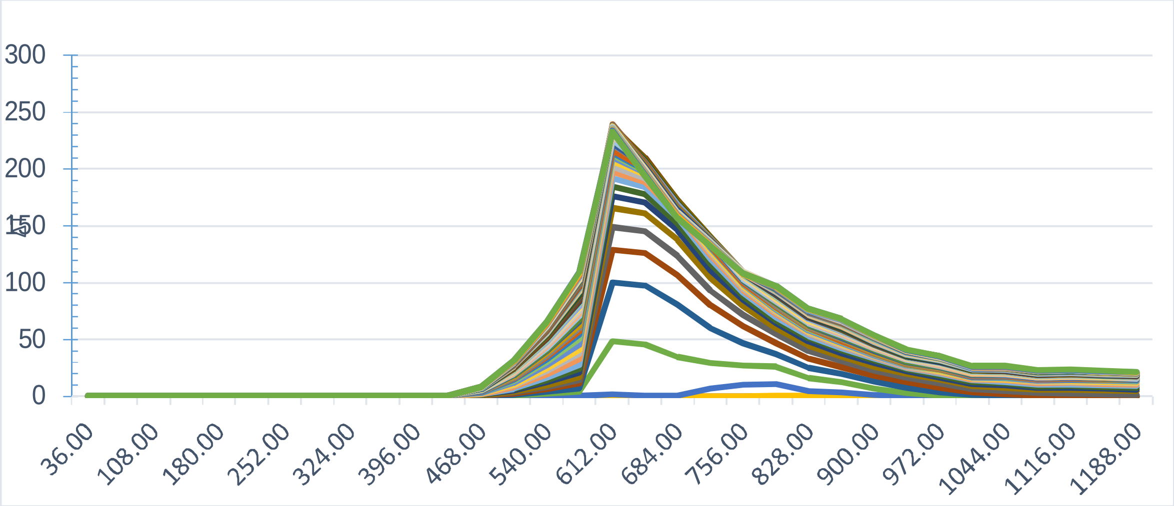

Fig. 6. Fire development scenario on upward ventilation flow:
Tunnel slope: 6%; The direction of combustion and ventilation products flow is the same; The air flow moves from right to left; The change in air temperature is given by thermocouple data (℃); Compared to the horizontal tunnel, a weaker backlayering is observed (see **Fig. 4**).

We have performed physical modeling in the range 0-10% with a 1% step. Fig. 6 shows the downward ventilation fire scenario for 6% model tunnel slope.

Fig. 6 shows that the peak air temperature of 245 ℃ no longer coincides with the fire source. It shifts to the side opposite to the movement of the ventilation flow. It seems that the intense movement of exhaust gases caused the temperature peak to shift to the direction of their movement. The backlayering length in this case is slightly reduced compared to the horizontal tunnel modeling results.

We also modeled inclined tunnels in the case when ventilation was switched off and both, the fresh air aupply to the fire source and flue gas diversion were provided by natural means – traction caused by fire. We assume that the velocity developed by the ventilation flow in this case, provided that the effect of aerodynamic resistance is excluded, is equal to the critical velocity. This is also confirmed by the fact that if we give the ventilation flow a similar velocity with downward mechanical ventilation, there will be no backlayering.

For the model of a tunnel with a slope of 3% in terms of natural ventilation, the picture of fire development is presented in Fig. 7.

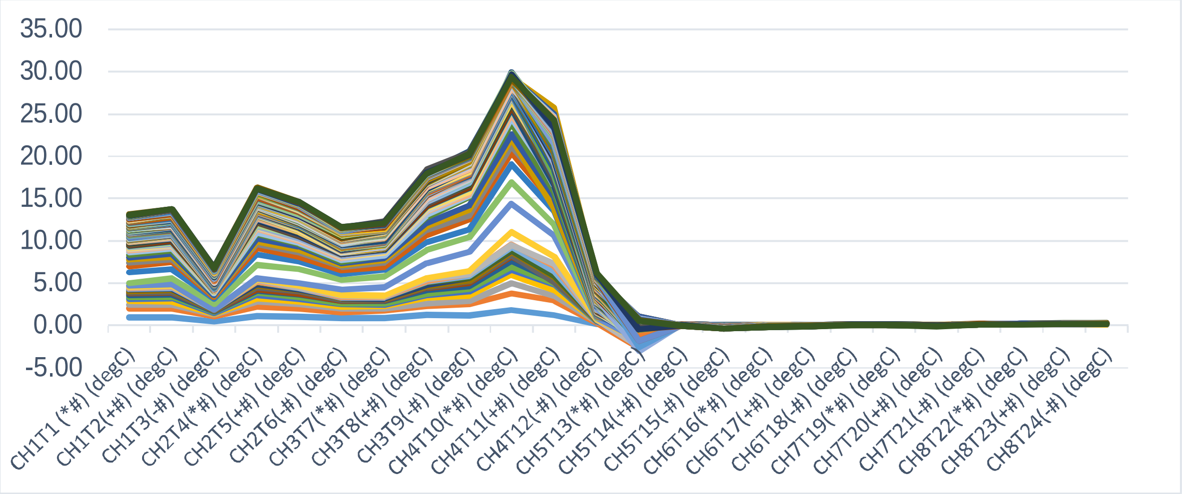

Fig. 7. Fire development scenario on upward ventilation flow of natural traction: Tunnel slope: 3%; The direction of movement of combustion products and ventilation is the same; The air flow moves from right to left; The change in air temperature is given as thermocouple data (℃).

As it can be seen from the presented material, in the case of downward ventilation flow, when the combustion products have the opposite direction of movement to the net ventilation flow, a weaker ventilation flow is expected after algebraic addition of the flows, which should be taken into account when designing emergency ventilation. This will allow avoiding the aforementioned ventilation design errors, thereby ensuring safe operation of tunnels and more reliably saving lives.

4. Conclusion

The primary conclusion of the presented research is the fact that the reference literature on fire ventilation calculation in road tunnels in practically all developed countries of the world a priori assumes the use of critical velocity directly indicating its numerical values depending on the strength of fire. Moreover, despite the long history of using critical velocities, we believe that fire ventilation designs should not be designed on the basis of critical velocities alone. Tunnel specifics and other important parameters (topology, location, climatic conditions, traffic patterns, and others) should be considered. Tunnel service personnel must prepare all possible fire scenarios in advance and have a clear algorithm of emergency response actions. To achieve success in this endeavor, we attach great importance to the results obtained in this work. In particular, the separation of the throttle effect from the result caused by the algebraic summation of mechanical and thermal flows. Physical modeling studies have also been carried out to show the nature of backlayering length variation and the ability to easily and reliably determine the critical velocity in inclined tunnels in case of natural traction.

ACKNOWLEDGEMENTS

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ხანძრის განვითარების სცენარები სხვადასხვა დახრილობის გვირაბის ფიზიკურ მოდელებზე

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რეზიუმე

კრიტიკული სიჩქარე რჩება ერთ-ერთ ყველაზე მნიშვნელოვან საპროექტო პარამეტრად საავტომობილო გვირაბების საგანგებო ვენტილაციის დამუშავების თეორიასა და პრაქტიკაში. აღსანიშნავია, რომ მხოლოდ აღნიშნულ სიდიდეზე პრაქტიკის დაფუძნებამ შესაძლებელია მიგვიყვანოს სერიოზულ შეცდომამდე. ამიტომ საჭიროა კონკრეტული გვირაბის სხვა მნიშვნელოვანი მაჩვენებლების გათვალისწინება და მოქმედების ცხადი ალგორითმის წინასწარი დამუშავება საგანგებო სიტუაციის მართვისათვის. ნაშრომში რიცხვითი და ფიზიკური მოდელების საშუალებით შესწავლილია სხვადასხვა სიმძლავრის ხანძრის განვითარების სცენარები. გაანალიზებულია ხანძრის გავლენით გვირაბში მოსალოდნელი აეროდინამიკური წინაღობის ბუნება. კერძოდ, ერთმანეთისაგან გამიჯნულია დროსელის ეფექტითა და ნაკადების ალგებრულად შეკრებით გამოწვეული ვენტილაციის სიჩქარის შემცირება. ლაბორატორიულ პირობებში, ფრუდის კრიტიკული რიცხვის მხედველობაში მიღებით, უჟანგავი ლითონის ფურცლებისაგან დამზადებულ გვირაბის მოდელზე შესრულებულია ხანძრების მოდელირება და ნაჩვენებია უკუდინების სიგრძის ცვალებადობის ხასიათი გვირაბის დახრილობის მიხედვით. ნაშრომში ნაჩვენებია, რომ ხანძარი არა მხოლოდ ვირტუალურად „ამცირებს“ გვირაბის კვეთს, არამედ ჰაერის ნარევის სიმკვრივის ცვალებადობის ხარჯზე აღძრავს დამატებით წევას, რომელიც დაღმავალი ვენტილაციის შემთხვევაში ვენტილატორების საპირისპიროდ იმოქმედებს. ნაჩვენებია აგრეთვე, რომ დახრილ გვირაბებში, გამორთული ვენტილაციის პირობებში, როცა ხანძრის შემთხვევაში მოქმედებს მხოლოდ ბუნებრივი წევა, შესაძლებელია საიმედოდ განისაზღვროს ვენტილაციის კრიტიკული სიჩქარის რიცხვითი მნიშვნელობა.

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