

Justification of Engineering Solution on Rebuilding Severomuysky Railway Tunnel Ventilation



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Abstract The purpose of this study was to develop proposals on upgrading heating and ventilation systems of the Severomuysky Railway tunnel with respect to rolling stock's traffic increase. Field studies of operating heating and ventilation systems were performed in winter to this end. Field studies included measurements of the velocity and air temperatures distribution lengthwise of the tunnel during absence period train and in the period of train moving. The main factors determining heating and ventilation regimes were defined and technical solutions were proposed for further development of the existing systems. On the basis of theoretical and empirical data, the upgrade solutions of the heating and ventilation systems were justified in the event of double increase of rolling stock traffic.

Keywords Railway tunnel · Ventilation · Heat regime · Unit-heater · Amount of traffic · Piston effect · Air consumption · Automatic gate · Equivalent equilibrium volumetric activity of radon

1 Introduction

Severomuysky railway tunnel (SMT), built-in 2003, is the longest tunnel in Russia [1]. In order to ensure safe operation of the tunnel, a ventilation system is used that provides an adequate air supply during an annual period and distributes the air over the traffic tunnel, service tunnel, shafts, shaft sidings and crossings and functions alongside with an outdoor air system in winter until positive temperature establishes [1, 2].

The requirements towards the heating and ventilation systems determined the possibility of icing and fogging prevention [3] as well as the decrease of volumetric activity of radon in air of mining workings [4].

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© Springer Nature Singapore Pte Ltd. 2020
A. Petriaev and A. Konon (eds.), *Transportation Soil Engineering in Cold Regions*,
Volume 1, Lecture Notes in Civil Engineering 49,
https://doi.org/10.1007/978-981-15-0450-1_54

Trains pump large amounts of cold outdoor air into the tunnel due to a piston effect [5–9], such that the air travels considerable distances in the direction of train movement from each tunnel portal. Additionally, tunnel's air is cooled as a result of heat exchange with train surfaces temperature of which equals outdoor air temperature. Since it was impossible to eliminate or mitigate the piston effect of a moving train and in order to maintain positive temperature in the tunnel, an approach compensating for the cold pumped by trains was used when there were no trains travelling [1, 2].

Air is supplied into SMT's mine workings by main ventilation fans, which are installed in a crossing that connects the ventilation shaft and traffic tunnel, alongside fans used for distributing air between the traffic and service tunnels [1]. An important element of the ventilation system is portal gates that are used to control air flows [2].

Geometry of the SMT mine workings is available in [1].

During the winter season the outdoor air entered the tunnel by means of the natural draught [10–13] or/and fans as well as the piston effect from the trains through the tunnel portals and it was removed through the ventilation shaft.

During the initial period of operation of the SMT, outdoor air heating was performed by unit-heaters located in ventilation buildings next to the tunnel portals and by additional unit-heaters installed in dedicated chambers 250–300 m away from the west and east portals.

In spite of the fact that without trains the temperature of the air being heated by unit-heaters reached 35–45 °C, this air moving towards the ventilating shaft brought cold air into the tunnel caused by trains at distances from the portals exceeding 3000 m.

Regular cross direction movement of the trains created in the middle of the tunnel an area of lower temperatures compared to those after unit-heaters. With the outdoor air temperature being –30 to –35 °C, the temperature in the area dropped below 0 °C, what resulted in icing.

For this reason, it was necessary to redistribute unit-heaters along the tunnel by means of deploying additional heat-up systems 3520 m away from the east portal and 4370 m from the west portal.

Winter 2017 field studies included efficiency evaluation of the existing heating and ventilation equipment, finding its weaknesses as well as main opportunities for upgrading of heating and ventilation systems in the event of a double increase in rolling stock traffic.

2 SMT's Heating and Ventilation System Study

2.1 The Purpose and Task of the Study

The purpose of the study was to determine actual aerodynamic and heat parameters of the heating and ventilation systems.

The tasks to be solved:

- To define actual air consumption distribution per an SMT mine workings;
- To study the piston effect created by a freight train depending on different position of the portal gates;
- To evaluate unit-heater efficiency installed next to portals;
- Measuring air temperature distribution along the tunnel with units installed for local air heating;
- To measure volumetric activity of radon in the traffic and service tunnel.

2.2 The Results of Measuring Air Consumption and Air Movement Directions During SMT's Operation

Air consumption and its movement directions in SMT mine workings were determined by means of air flow measurement along mine workings according to methodology [14]. To measure air speed and its thermodynamic parameters MES-200 thermal anemometer [15] was used. Air flow directions through mine workings according to the measurements are shown in Fig. 1.

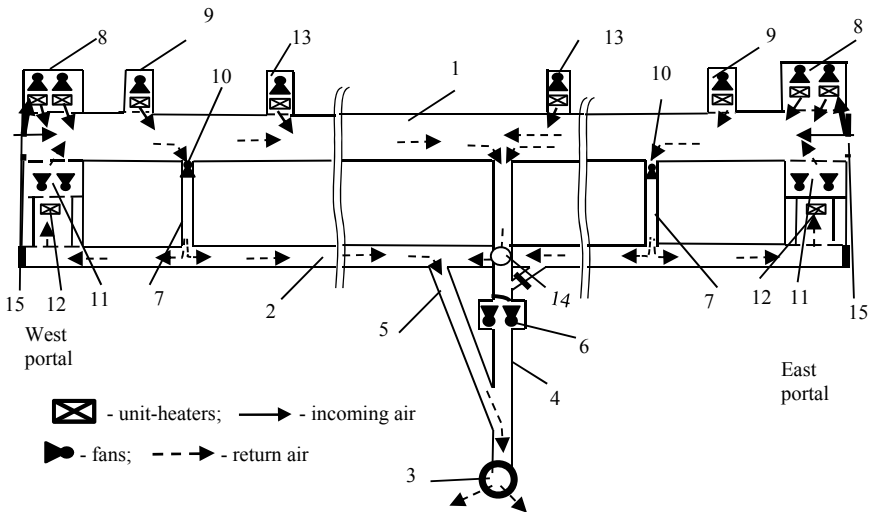


Fig. 1 Ventilation scheme for Severomujsky tunnel in winter: 1—traffic tunnel (TT); 2—service tunnel (ST); 3—ventilation shaft (VSh); 4—crossing (Cr); 5—bypass tunnel (BT); 6—ventilation room with main fans (VR); 7—ventilation crosscut (VCrc); 8—ventilation building (VB); 9—additional unit-heaters (AH); 10—fans for air-splitting (Fsp); 11—fans for recirculation air (Frec); 12—unit-heaters for recirculation air (UHrec); 13—local unit-heaters (LH); 14—air staple shaft (Assh); 15—automatic gates (AG)

According to the measurements, outdoor air enters the traffic tunnel (TT) through the West and East portals, then it gets heated up by unit-heaters located in ventilation buildings (VB) and by additional unit-heaters (AH). As soon as the air reaches ventilation crosscuts (7), one part of it is sent to the service tunnel where it was split into two flows. One of the flows moved towards a bypass tunnel (BT) where it mixed with air from the traffic tunnel (TT). Another air flow moved through the service tunnel towards ventilation buildings (VB) at the West and East portals, then it was heated up by unit-heaters (12) and sent into the traffic tunnel (TT) by fans (11).

Another part of the air after the ventilation crosscuts (VCrc) moved through the traffic tunnel (TT) to the crossing (Cr) and forth where was bleed off through an air staple shaft into the service tunnel (ST).

After mixing, the whole air volume from the traffic tunnel (TT) and service tunnel (ST) was sent through the bypass tunnel (BT) into the ventilation shaft (VSh) to reach the surface.

During the field study, main fans (VR) were off and their inputs were shut with dump doors. Airflow at the portals without trains was 35–50 m³/s, service tunnel areas between the ventilation crosscuts and ventilation buildings was 6–19 m³/s, the airflow that reached surface leaving the shaft amounted to 50–70 m³/s. The difference between the airflow was caused by the piston effect that could not be avoided during the field study while the railway tunnel was in operation. Moreover, during observations, it was noted that not only the absolute air consumption values, but also the direction of movement changed inside both the traffic (TT) and service tunnels (ST).

2.3 Studying the Piston Effect Created by Moving Rolling Stock in the Tunnel

In order to evaluate the piston effect of rolling stock air speed (consumption) was measured that entered the tunnel through portal sections. The measurements were performed at the East portal alongside a freight train moving westwards (the direction of a natural draught was from West to East). In order to eliminate the influence of portal's resistance on the velocity field, the measurement point was located at a distance 10 times exceeding the hydraulic diameter of the tunnel.

Air speeds were recorded every 30 s in the measurement point during the process. The measurements were taken before the train entered the tunnel and immediately it reached the test point. The train consisted of 85 cars. Average train's speed in the tunnel was approximately 51 kph. The results of the measurement are shown in Fig. 2.

The analysis of the measurements showed that the train by entering the portal caused the natural air flow eastwards direction to change (negative air consumption value on the diagram). A significant drop in air consumption was caused by shutting the East portal gates after the train passed by (point 1). As the train moves westwards,

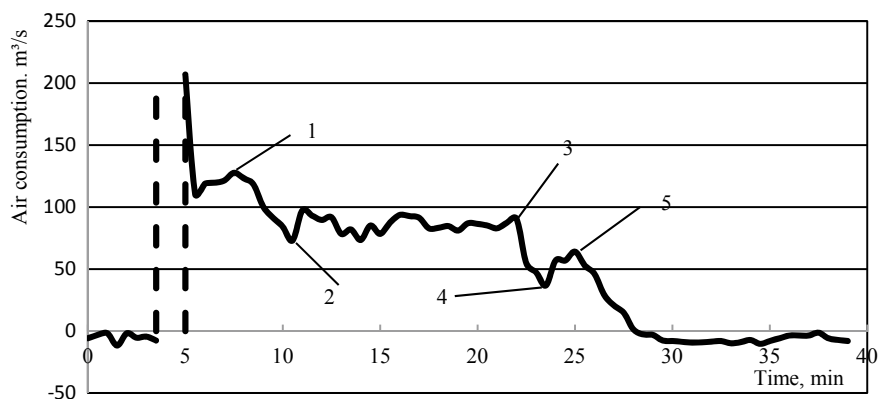


Fig. 2 Behaviour of consumption on entering the tunnel with a moving rolling stock (dashed lines indicate the step time of the rolling stock at the test point)

air consumption continuously goes down. After the West portal gates were open, the air flow at the measurement point grew by $20 \text{ m}^3/\text{s}$ (point 2). The area of the graph between point 2 and 3 shows the behaviour of the amount of air entering the tunnel with a moving train, with open West portal gates. As the train leaves the tunnel, air consumption drops (point 4). As the train completely leaves the tunnel with open West portal gates, air consumption grows approx. by $25 \text{ m}^3/\text{s}$ (point 5) due to a lower aerodynamic resistance of the tunnel. After the West portal gates are shut, air consumption drops to zero and air begins its eastward movement again. Average air consumption calculated during the existence of the piston effect was $82.2 \text{ m}^3/\text{s}$, and the piston effect lasted for 27 min.

Comparing the piston effect in winter and in summer [2] with the above-mentioned settings of portal gates opening/closing shows that average air consumption nearly doubles with the gates open. Calculations performed according to paper [5] regarding the field study conditions revealed that the estimated value of the average air consumption is $74 \text{ m}^3/\text{s}$ what deviates from the empirical data only by 10%.

2.4 Studying Temperature Conditions at the Portal Areas

Air temperatures before and after the unit-heaters installed in the ventilation building (VB) at the East portal were measured without trains and with trains leaving or entering the East portal. Alongside measuring the temperature, air volumes entering the unit-heaters were measured. Data analysis makes it is possible to conclude that the direction of train's movement regarding the portal with unit-heaters exerts ultimate influence on the resulting air temperature. When a train enters the portal bringing outdoor air to the unit-heaters, return air temperature from the unit-heaters does not exceed $7\text{--}13 \text{ }^\circ\text{C}$. When a train leaves the portal, unit-heaters are supplied with tunnel

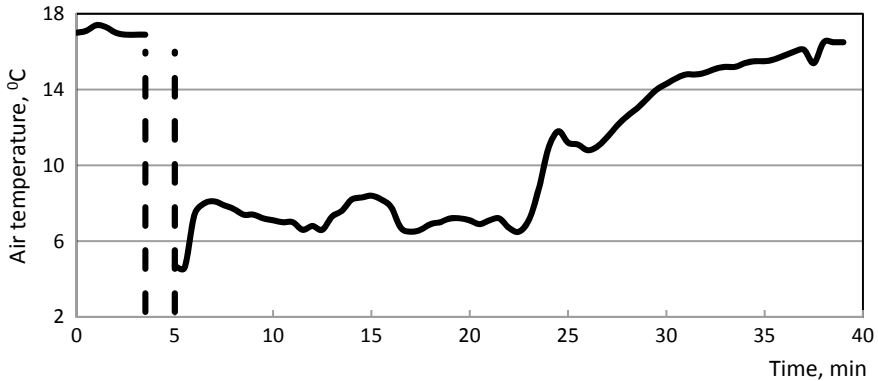


Fig. 3 Air temperature changes at the entrance to the tunnel with a moving train (dashed lines indicate the step time of the rolling stock at the test point)

air with average temperature amounting to the average temperature of an adjacent tunnel section. As a result, unit-heaters' output temperature reaches 30–43 °C and the heated air is removed from the tunnel. The amount of air supplied to the unit-heaters does not change depending on the train's direction and it is 13–15 m³/s.

Thus, a unit-heater located at the exit portal virtually heats-up only the portal area and the outdoor air outside the portal, what decreases its energy efficiency.

Besides the efficiency of the portal unit-heaters average temperatures at the portal areas were measured while there was a train inside the tunnel. The cross-section where the temperature was measured at coincides with the airflow measuring points. According to the data analysis shown in Fig. 3, air temperature in the tunnel before a train entered it was 17 °C.

After the train passes the measurement point, usually there is a significant drop of 13 °C. The temperature remains nearly constant for 18 min after the train leaves. It goes back to its initial values in 35–40 min later.

2.5 *Temperature Measurement Results of the Air Distributed Along the Tunnel*

The changes in air temperature along the tunnel were measured for the same heating system but after additional unit-heaters were installed at 3520 and 4370 m away from the East and West portals correspondingly (Fig. 4).

Data analysis showed that using the distributed heating system allowed increasing the temperature in the middle section of the tunnel up to positive values where it used to go below 0 °C.

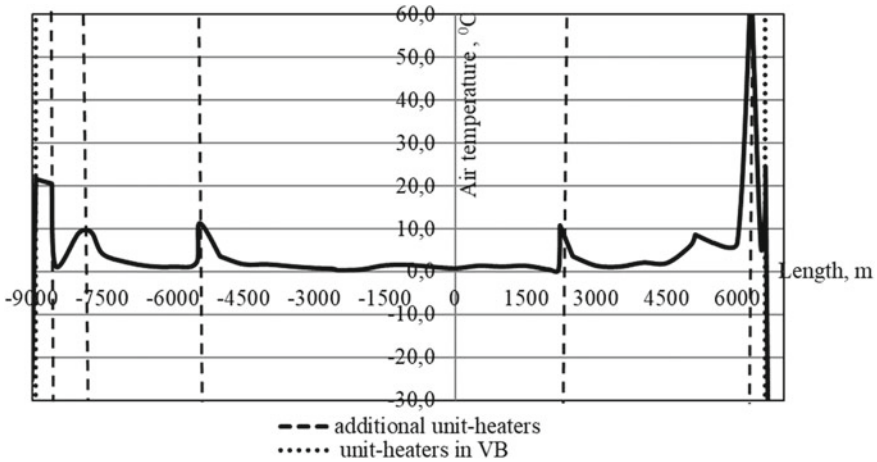


Fig. 4 Air temperature distribution along the tunnel

2.6 Evaluating Volumetric Activity of Radon in the Traffic and Service Tunnels

The evaluation of radiation environment was performed by equivalent equilibrium volumetric activity of radon (EEVARn) in the traffic and service tunnels.

The traffic tunnel shows normal values of EEVARn [4], but the service tunnel showed a 2–2.5 times excess of EEVARn, especially in the air entering the bypass tunnel (BT). The reason for this is regular changes in air movement direction due to the piston effect and air recirculation among the portals and ventilation crosscuts that lead to the accumulation of radon in the air.

The comparison of average volumetric activity of radon in tunnel’s mine workings and the volumes of water drained from the tunnel showed a linear correlation between those two values with a coefficient no less than 0.7.

This means it is possible to stabilize radiation environment not only through ventilation improvements but also decreasing the amount of drain water containing radon in the tunnel.

3 Approaches to Rebuilding Heat and Ventilation Systems Upgrading in the Event of Rolling Stock’s Traffic Increase

Field studies of existing heat and ventilation systems in the SMT helped to find out the details of their operation with current rolling stock traffic and to suggest technical solutions how to upgrade the systems in the event of a double increase in the traffic.

In order to define heat and ventilation systems' parameters in the event of rolling stock's traffic increase, a simulation model was created to study the aerodynamics of the tunnel's ventilation depending on different traffic intensity and speeds in the traffic tunnel (TT) [16, 17]. The considered cases included one or two trains travelling with the speed of 60 and 80 kph. Simulation results showed that the average amount of air entering the tunnel when the piston effect was online and the train speed was 60 kph was $70 \text{ m}^3/\text{s}$ in case of one train travelling and changed to $96 \text{ m}^3/\text{s}$ in case of two freight trains. If the speed was 80 kph, the amount of air entering the tunnel increased from $110 \text{ m}^3/\text{s}$ to $120 \text{ m}^3/\text{s}$ correspondingly. Those data were used to calculate air heating system capacity [18, 19]. It turned out that in case of a double increase in rolling stock's traffic the capacity of the heat system needs to be increase two and threefold depending on train schedule and speeds.

On the basis of the field studies and simulations, a number of technical solutions were proposed for operating the SMT with the increased rolling stock's traffic meeting the requirements from Sect. 2. The solutions include:

- deploying additional heat systems along the tunnel and simultaneous increase of unit-heaters' capacity at the portals;
- controlling the performance of unit-heaters at the exit portals to decrease energy consumption;
- ventilation the service tunnel with heated outdoor air by a separate ventilation system instead of ventilating the tunnel by means of air recirculation.

4 Conclusion

The following information was found on the basis of field studies and simulations:

- the main factors affecting the operation of current heat and ventilation systems of the outdoor air are travelling freight trains up 1200 m long at a speed up to 60 kph and the temperature difference between the tunnel portals of 10–15 °C, extremes being from –25 to –35 °C;
- regular changes in air movement directions due to the piston effect and air recirculation among the portals and ventilation crosscuts, what results in accumulating radon in the air, should be acknowledged as the reasons for the increase in equilibrium volumetric activity of radon in tunnel's mine workings;
- to meet the requirement of preventing icing in the event of a double increase in rolling stock's traffic, it is necessary to enhance the capacity of the heat system by 2–3 times depending on train schedule and speeds;
- the solutions proposed allow meeting the requirements that guarantee safety of the rolling stock in case of increasing its traffic.

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