

Constructing a generalized network design model to study air distribution in ventilation networks in subway with a single-track tunnel

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Abstract. In focus are the features of construction of the generalized design model for the network method to study air distribution in ventilation system in subway with the single-track tunnel. The generalizations, assumptions and simplifications included in the model are specified. The air distribution is calculated with regard to the influence of topology and air resistances of the ventilation network sections. The author studies two variants of the subway line: half-open and closed with dead end on the both sides. It is found that the total air exchange at a subway station depends on the station location within the line. The operating mode of fans remains unaltered in this case. The article shows that elimination of air leakage in the station ventilation room allows an increase in the air flow rate by 7–8% at the same energy consumption by fans. The influence of the stop of a train in the tunnel on the air distribution is illustrated.

Tunnel ventilation as the basic component of the life-support system in the subway should meet the requirements and standards of SP Subways [1] in routine and emergency situations. Mathematical network model of the ventilation system was elaborated on the base of the reviewed design and construction documents on air flow motion in acting subways with the objective to investigate air distribution in subway infrastructure units in terms of Novosibirsk Metro as a case study. To verify compliance of design data and parameters of operating units the researcher undertook field survey of ventilation facilities in stations and track sections. The specified data served the base to calculate aerodynamic resistance of network branches [2, 3]. The subway ventilation network represents the integrated system where operating fans exert substantial influence on airflow parameters in different points of the network. The objective of the present research is to identify components constitutive for air distribution and fan operation modes in the network.

The generalized scheme of the ventilation network is worked out. It includes repeating modules: station passenger underpasses, station ventilation rooms, ventilation chambers in track sections, and connecting track tunnels to establish general air-distribution regularities in terms of the ventilation network in Novosibirsk subway (Figure 1). Aerodynamic resistance in sections of these modules is computed as averaged values for respective sections of the ventilation network consisting of Novosibirsk subway stations and tunnels.



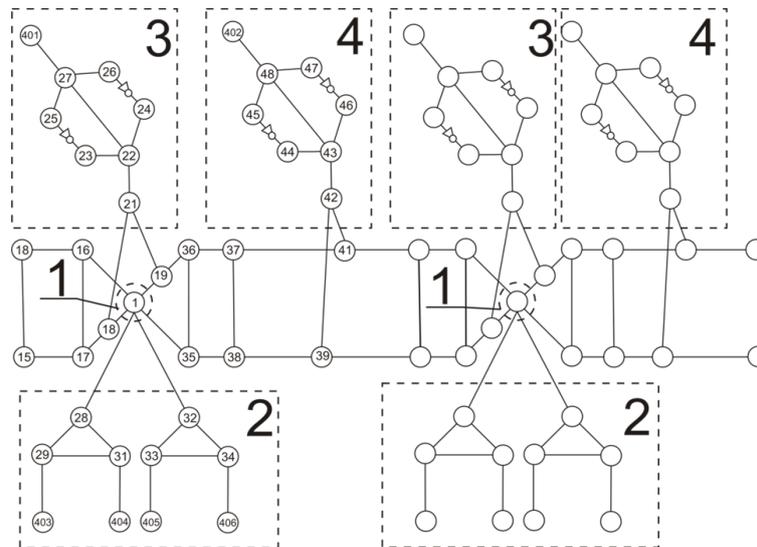


Figure 1. Generalized computed ventilation system scheme of a subway line: 1 – station platform; 2 – station pedestrian passways; 3 – station ventilation chamber; 4 – ventilation chamber in a track section; circled numbers are numbers of modules of the computed ventilation network

The application of the generalized model permits to eliminate influence of specific peculiarities of different stations on air distribution.

The standard station has two entrance halls with two exits per a hall. In exits there is one row of 4-valve doors with preset opening angle of 20° , in the entrance to the booking hall there is also a row of 4-valve doors with preset opening angle of 20° . The principal resistance source is doors, it amounts to $0.03 \kappa\mu$ (sections 403-29, 29-28, etc.).

The standard station ventilation chamber is equipped with two fans without diffusers, there are built-in splitter silencers made of slag blocks before and after fan facilities, there is a single kiosk, air passes are in both platform ends with an additional air pass through under-platform channel. The principal resistance is outlet of the ventilation kiosk and amounts to about $0.003 \kappa\mu$ (section 401-2); exits to tracks: 0.01 for the nearest exit and 0.013 for the far exit.

The standard ventilation chamber at a track section is equipped with two fans without diffusers; there are built-in splitter silencers made of slag blocks before and after fan facilities, there is a single kiosk, air passes to tracks are through both tunnels separately through a channel between tracks. The principal resistance is outlet of the ventilation kiosk and amounts to about $0.003 \kappa\mu$; exits to tracks are $0.0025 \kappa\mu$ per each exit.

The standard one-track tunnels are lined with concrete tubing of 5.1 m in diameter, the ventilation connexion is 20 m in length, half-track section length is 500 m.

There are 8 stations per a line it is the minimal quantity for the proper control of mutual influence of air distribution in the line [4].

The subway line exists in two versions: semi-open with one dead end and another end coming out to open air and dead-type confined with both dead ends.

The ventilation network operating at summer mode approved for Novosibirsk subway: VOMD-24 station fans operate in a draft ventilation mode, one per a ventilation chamber; the second fan is

switched off, its gate is closed; fans in track sections are out of operation, their gates are open; the gates of civil defense significance are open.

Operation of tunnel fans was modeled with the use of averaged aerodynamic characteristic of fan facilities calculated based on full-scale measurements. Thereto, resistance of inlet and outlet elements was taken into account in aerodynamic characteristic of fan facilities with respective improvement of accuracy of calculations and better compliance with the actual object. This characteristic is described by relationship:

$$P = -0.0488 \cdot Q^2 + 1.31 \cdot Q + 55,$$

where P is static pressure, Pa; Q is air flow rate, m^3/s .

The use of the static characteristic is justified by the fact that the dynamic component of the fine pressure developed by VOMD-24 tunnel fan is practically completely lost at fan outlet to the discharge section of the ventilation chamber because of imperfection of outlet components and lack of a diffuser.

The air exchange at station platform and its components: air in-takes from a tunnel and passenger passways of the station were selected as basic parameters of air distribution.

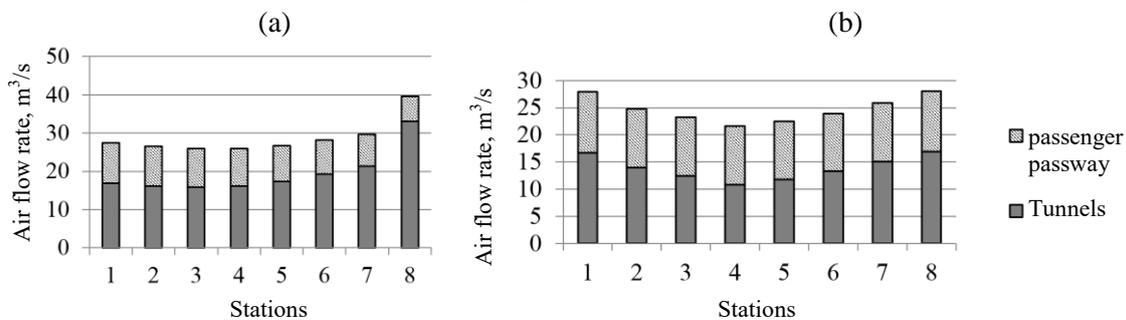


Figure 2. Air flow rate through the station platform room: half-open line, (a) an outlet to open air at the 8-th station, (b) dead line.

In Figure 2a the cumulative air exchange diagram is plotted for a station of a half-open line. It is explicit that air flow rate tends to grow in approach to the open air exit which locates after the 8-th station. Growth of air flow rate is realized thanks to air supply from a tunnel, the air supply volume is twofold greater than volumes in the first and blind-end stations. Herewith, air flow rates of the fans in the entire line do not actually change and range within $45.7\text{--}45.9 \text{ m}^3/\text{s}$.

In Figure 2b the cumulative air exchange diagram is plotted for stations of the blind (butting) line. It is obvious that air flow rate in opposite stations is approximately the same (small difference is due to unsymmetrical air outlets on the way from station ventilation chambers) The air flow rate in blind sections is higher thanks to air supply from the tunnel. The air flow rates for fan facilities in the entire line are the same and amount to $45.7 \text{ m}^3/\text{s}$.

Influence of variations in resistance of block sections:

–under variations in resistance of the second idle fan in the station ventilation chamber from 0.666 to 150 $\kappa\mu$ in the half-open line the air flow rate at stations increased by 7–8%, thereto the air flow rate in the fans remained within $45.1\text{--}45.9 \text{ m}^3/\text{s}$, in other words, it altered inappreciably. Thus, reduction in leakage through the idle fan provides an essential air exchange boost at the station without increase in energy consumption for ventilation;

– mounting of an additional row of doors increases resistance of sections with doors from 0.03 to 0.06 $\kappa\mu$, herewith in the half-open section of the dead-end station the air flowrate lowered by 7.3%,

and at the eighth closest-to-open-air station it increased by 9.1%. Production capacity of fan facilities remains the same within 45.6–45.9 m³/s;

– enclosure of entrance hall at the fourth station (Figure 3) leads to notable redistribution of air exchange at neighboring stations: air exchange is lower by 13.5% at the third station and is higher by 16.1% at the fifth station. The fan performance did not change and remained within 45.7–45.9 m³/s;

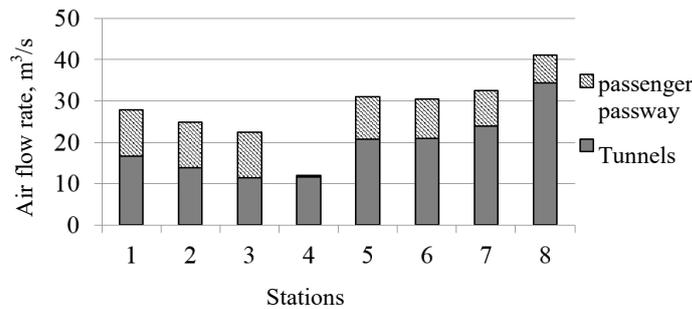


Figure 3. Air flow rate through station platform: half-open line, closed entrance hall at the fourth station

– variation in resistance of tunnel sections (in terms of a train made a stop in a tunnel) was examined in sections between stations 1 and 2, 3 and 4, 7 and 8 in half-open line (Table 1) and stations 1 and 2, 3 and 4 for a dead-end line (Table 2) considering its symmetry (Figure 4). Air distribution was modeled provided that the train stopped on both sides from the ventilation chamber; the air flow rates were considered at all four tunnel sections. It was concluded, air exchange at stations did not actually change, or changed by no more than 2–3%. The fan performance remained the same within 45.7 for the dead-end line and 45.7–46 m³/s for the half-open line. Air flow rates in the test tunnel section altered appreciably, the resultant difference was about 1200% with an air flow reversed in discrete cases.

Table 1. Half-open line

Train location	Branches	Basic flow rate	Version			
			1)		2)	
			<i>Q</i> , m ³ /s	Δ , %	<i>Q</i> , m ³ /s	Δ , %
Track section 1–2*	a	–9.9	–4.7	52.5	–10	–1
	b	0.6	5.5	–816.7	0.5	16.7
	c	–9.9	–14.6	–47.5	–9.8	1
	d	0.5	–3.9	–680	0.7	–40
Track section 3–4	a	–9.6	–4.5	53.1	–9.6	0.0
	b	0.4	5.2	–1200	0.5	–25.0
	c	–9.6	–13.9	–44.8	–9.6	0.0
	d	0.4	–3.7	–825	0.3	25.0
Track section 7–8	a	–17.5	–8.1	53.7	–14.3	18.3
	b	–10.2	–2.6	74.5	–5.5	46.1
	c	–17.6	–23.5	–33.5	–19.6	–11.4
	d	–10.2	–15.0	–47.1	–13.3	–30.4

*track section between stations 1 and 2, hereinafter - respectively; *Q* – air flowrate, m³/s; Δ – difference between the basic and actual flow rates, %

Table 2. Blind line

Train location	Branches	Basic flow rate	Version			
			1)		2)	
			$Q, m^3/s$	$\Delta, \%$	$Q, m^3/s$	$\Delta, \%$
Track section 1-2*	a	-9.2	-4.5	51.1	-9.7	-5.4
	b	1.8	6.3	-250.0	1.3	27.8
	c	-9.2	-13.9	-51.1	-8.9	3.3
	d	1.8	-2.7	-50.0	2.2	-22.2
Track section 3-4	a	-6.6	-3.5	47.0	-8.1	-22.7
	b	4.3	7.1	-65.1	2.5	41.9
	c	-6.4	-9.2	-43.8	-5.2	18.8
	d	4.4	1.8	59.1	5.8	-31.8

*track section between stations 1 and 2, hereinafter – respectively; Q – air flowrate, m^3/s ; Δ – difference between basic and actual flow rates %

Conclusions

The principal aerodynamic resistance objects of subway with two-track tunnel are station doors, kiosks of ventilation chambers, exits to the tunnel in the station ventilation chambers.

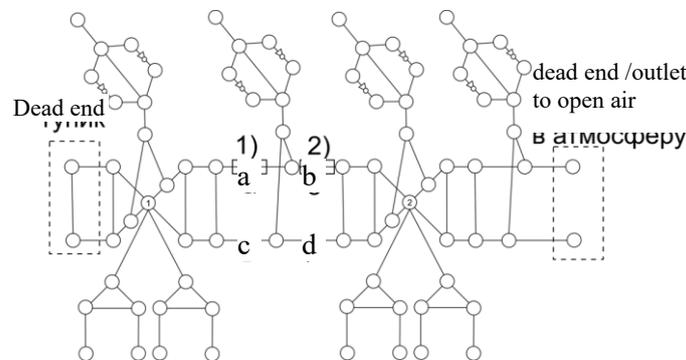


Figure 4. A train in tunnel section: 1), 2) are variants of train location in the tunnel; a, b, c, d are branches of the ventilation network where variations in the air flow rates were monitored.

Reduction in leakage through an idle fan facility allows higher air exchange at stations by 7–8% without extra energy consumption.

Variation in aerodynamic resistance of tunnel sections when trains stop in them affects insufficiently the air exchange at stations and the fan operation mode, but it is capable to alter an air flow rate in neighboring and parallel tunnel sections up to 1200% depending largely on a train location in the line.

The line topology, variations in branch resistance beyond ventilation chambers do not exert any appreciable effect on the fan operation mode.

References

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