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Integrated performance analysis of ventilation schemes for double-line subway tunnel

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Integrated performance analysis of ventilation schemes for double-line subway tunnel

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Abstract. The analysis of ventilation schemes for double-line subway tunnel uses criteria of operational economy and efficiency in routine and emergency modes. The longitudinal, transverse and longitudinal–transverse schemes ventilations are considered. It is shown that the most efficient and economic scheme is longitudinal ventilation in the routine mode and longitudinal–transverse ventilation in the emergency mode.

1. Introduction

Ventilation in subway tunnels is to remove harmful off-gases, as well as to maintain the preset air conditions and definite chemical composition. The major characteristics of a ventilation system inlet and outlet air flow rate which is to meet actual standards in the routine mode of a tunnel [1, 2]. In the emergency mode, a tunnel ventilation is to ensure safe evacuation of passengers and personnel from the zone of firing (smoke generation, gas pollution). To this effect, fresh air is fed in the escape to remove smoke and prevent smoke pollution of the other subway areas.

The international experience shows that double-line subway tunnels increasingly more frequently use the system of separate ventilation of tunnels and platforms [3]. The air distribution analysis in subways implies that tunnel ventilation is possible without ventilation chambers to be installed in the tunnel [4]. This considerably reduces capital cost due to decreased volume of underground construction, improves maintainability and accelerates troubleshooting.

2. Analysis of ventilation schemes for a double-line tunnel

Let us discuss variants of ventilation in a double-line tunnel:

—without an air duct—longitudinal ventilation (Figure 1a);

—with an air duct equipped with a baffle to divide fresh and disposal air flows—transverse ventilation (Figure 1b);

—unbaffled air duct (Figures 1c–1e)—hybrid longitudinal–transverse ventilation.

The criteria for the comparison of the listed ventilations include:

—aerodynamic parameters of fans (governed by air flow rate and loss);

—efficiency of operation in the emergency mode;

—operational economy.

The earlier research has found that the design flow rate of disposal air in the routine mode is mostly governed by excess heat in the tunnel. For heat loss in soil has minor influence on the heat balance, the air flow rates are approximately equal in the tunnel design in Figure 1. In the section composed of a tunnel and a platform in the Moscow Metro, the required air flow rate is 117.7 m^3/s [8].

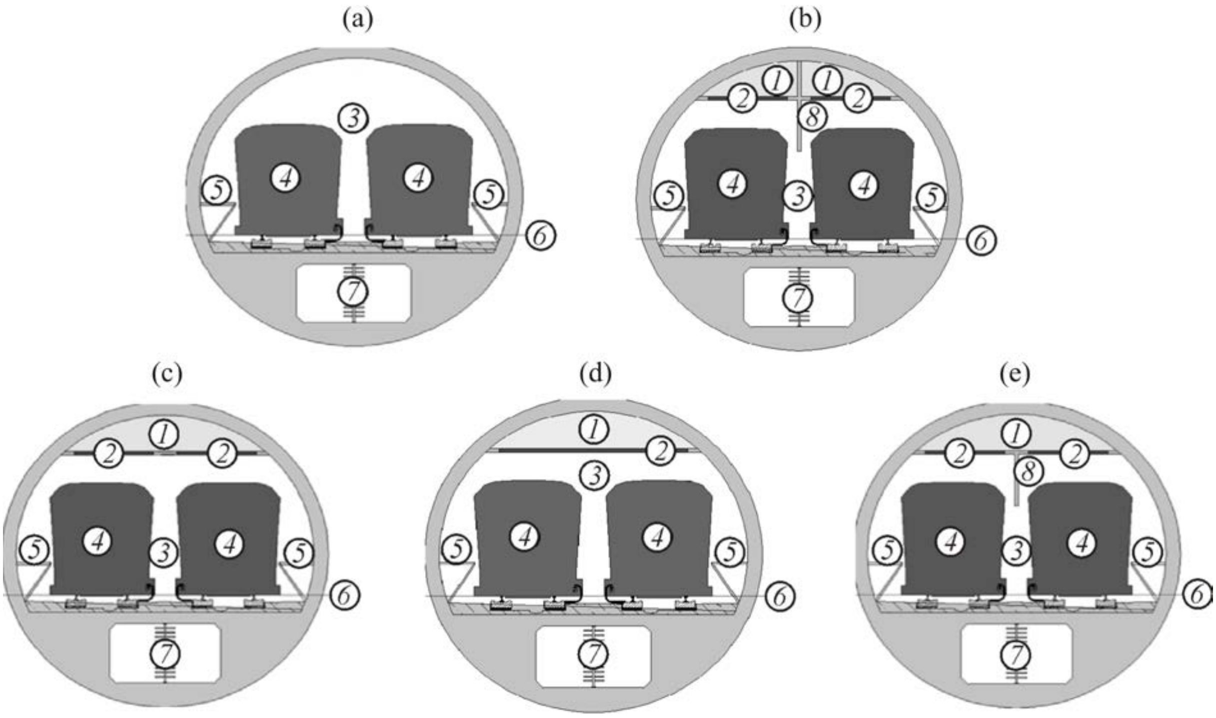

Figure 1. Double-line tunnel designs: *1*—air duct; *2*—hatch; *3*—tunnel; *4*—train; *5*—bench; *6*—level of head of rail; *7*—cable channel; *8*—line shield.

In the emergency mode, e.g., fire in the tunnel, ventilation is strongly required to ensure the design air flow rate in the escape so that to prevent spreading of smoke toward fresh air flow. This allows air flow not to be reversed, which ensures the safe escape. In a double-line tunnel, the highest velocity of the required air flow is 2.07 m/s [1]. Thus, for the tunnel design in Figure 1a, the required air flow rate is 87.6 m^3/s, Figures 1b and 1e—78.7 m^3/s, Figure 1c and 1d—80.9 m^3/s; this means that the air flow rate in the longitudinal ventilation

The design of the tunnel without an air duct in Figure 1a has a number of advantages: it is cheaper as there no expenses connected with the manufacture, installation, debugging, maintenance, etc. of the air duct; the air drag in the tunnel is lower, which brings in lesser blast pressure and electric energy spent for airing. The disadvantage of this design is the implementation of exclusively longitudinal ventilation. In case of emergency, passengers can only escape in the single direction off the fire source, which can result in fatality if cars get inflamed in the middle of a train.

For the passengers to evacuate in both directions from a fire source, it is required that fresh air is fed from both side toward evacuating people while gases of fire and smoke are removed from the scene of fire. Smoke is to be removed via a ventilation channel so that the evacuation routes are free from smoke. In this case, it is necessary to arrange the ventilation channel to ensure the longitudinal–transverse airing of the tunnel. Such tunnel designs are illustrated in Figures 1b–1e. The tunnels of such designs can be used for various purposes [5–7]. The advantages of the tunnel design in Figure 1e (with a line shield) are described and proved in [8].

Figure 2 depicts the longitudinal–transverse ventilation in a tunnel during fire and train stop in it: hatches *1* are opened above the burning car *2*; in the platform on the two sides of the emergency tunnel, air chambers *4* connected with the ventilation channel via valves *5* are switched into the mode of draught to remove smoke. Fresh air is fed from the two sides of the tunnel by air chambers *3* in the mode of air inflow toward evacuating people. This ventilation scheme conforms with the tunnel designs in Figures 1c–1e.

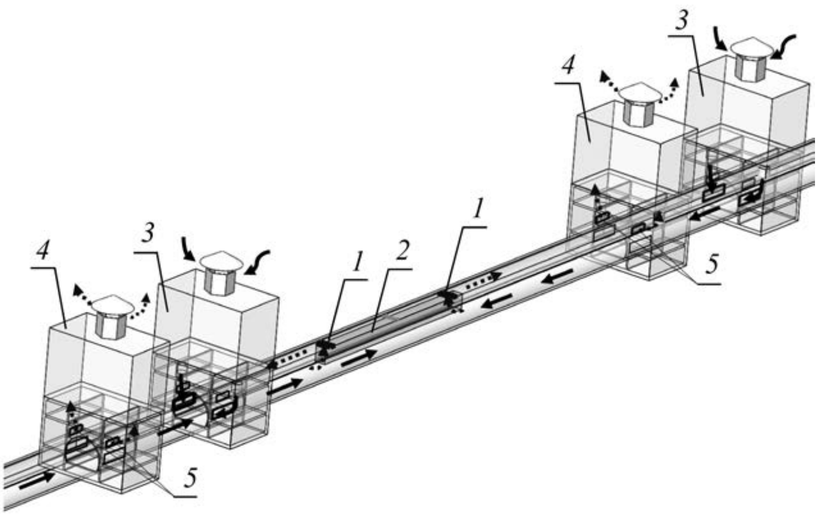

Figure 2. Schematic of smoke removal and fresh air supply in case of car fire and train stop in the tunnel: *1*—hatches to ventilation channel; *2*—emergency car; *3*—feeding air chamber; *4*—removing air chamber; *5*—connecting valves between the ventilation channel and air chambers.

Let us estimate effect of a ventilation design on the other aerodynamic parameter—pressure loss. The pressure loss ΔP in air flow along a long straight pipe are determined from the Darcy–Wesibach equation [9]:

$$\Delta P = \frac{\lambda \rho v^2}{2D_\text{h}} l \, ,$$

where λ is the fricition resistyance coefficient; ρ = 1.2 kg/m^3 is the air density in normal conditions; v is the air flow velocity, m/s; l—is the channel length, m; $D_\text{h} = 4F / \Pi$ is the hydraulic parameter of the tunnl, m; F is the cross section area, m^2; Π is the perimeter, m.

The friction resistance coefficient λ depends on the pipe roughness Re($k_\text{eqv} / D_\text{h}$), where $k_э$ is the absolute equivalent roughness of the channel surface, mm; it depends on the channel lining material. In a double-line tunnel, Re($k_\text{eqv} / D_\text{h}$) is always higher than 500 mm/m, and the friction resistance coefficient is found from the Shifrinson equation for totally rough pipes:

$$\lambda = 0.11 \left(\frac{k_\text{eqv}}{D_\text{h}} \right)^{0.25} .$$

Tables 1 and 2 describe pressure loss ΔP in the routine and emergency modes of operation, respectively, in a double-line tunnel 1 km long in case of different tunnel designs and ventilation schemes, as well as for half-tunnel (500 m long) air chambers of different design arranged in the tunnels. The pressure loss in the air chambers was disregarded, for they are similar in all schemes discussed and, according to [10], makes up to 70 % of the fan pressure.

Table 3 compiles values of air capacities in different routine and emergency ventilations (longitudinal, transverse and longitudinal–transverse).

Evidently, the transverse ventilation (Figure 1b) is inefficient due to high loss in friction (per 500 m of ventilation channel—1492 Pa in the routine mode and 667 Pa in the emergency mode), which is difficult to compensate using the mode fans currently in operation in subway tunnels. The presented parameters are characteristic of mine fans. In view of the fact that the required air flow rate in the routine mode exceeds the air flow rate in the emergency mode (for the tunnels equipped with the ventilation channel), it is expedient to use the longitudinal ventilation (Figure 3).

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Table 1. Geometrical parameters and pressure loss in friction in double-line tunnels and ventilation channels of different design in routine operation.

Description	F, m^2	Π, m	D_h, m	v, m/s	Q, m^3/s	K_{eqv}, mm	ΔP, Pa
Double-line tunnel without air duct—longitudinal ventilation (Figure 1a)	42.3	26.56	6.37	2.8	117.7	2	61
Double-line tunnel witht air duct—longitudinal ventilation (Figures 1c and 1d)	39.1	28.16	5.55	3.0			42
Double-line tunnel witht air duct—longitudinal ventilation (Figures 1b and 1e)	38	30.4	5	3.1			51
Ventilation channel, concrete—longitudinal–transverse ventilation (Figures 1c–1e)	9.17	15.85	2.31	6.4	58.85		569
Ventilation channel, steel—longitudinal–transverse ventilation (Figures 1c–1e)						0.1	269
Ventilation channel, steel—transverse ventilation (Figure 1b)	4.45	9.56	1.86	13.2			1492

Table 2. Geometrical parameters and pressure loss in friction in double-line tunnels and ventilation channels of different design in emergency operation.

Description	F, m^2	Π, m	D_h, m	v, m/s	Q, m^3/s	K_{eqv}, mm	ΔP, Pa
Double-line tunnel without air duct—longitudinal ventilation (Figure 1a)	9.17	15.85	2.31	4.4	40.45	0.1	127
Double-line tunnel witht air duct—longitudinal ventilation (Figures 1c and 1d)				4.2	39.35		120
Double-line tunnel witht air duct—longitudinal ventilation (Figures 1b and 1e)	4.45	9.56	1.86	8.8	39.35		667
Ventilation channel, concrete—longitudinal–transverse ventilation (Figures 1c–1e)	42.3	26.56	6.37	2.07	87.6	2	33
Ventilation channel, steel—longitudinal–transverse ventilation (Figures 1c–1e)	39.1	28.16	5.55		80.9		20
Ventilation channel, steel—transverse ventilation (Figure 1b)	38	30.4	5		78.7		23

Table 3. Air capacity of tunnel ventilations in routine and emergency operation.

Ventilation	Tunnel ventilation capacity, kW	
	Routine	Emergency
Longitudinal	7.2	2.9
Transverse	175.6	52.5
Longitudinal–transverse	18.3	6.5

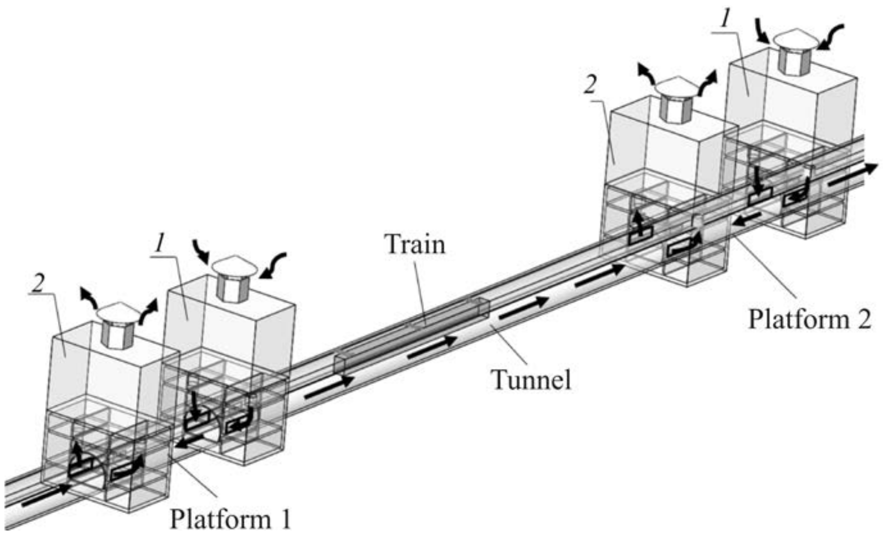

Figure 3. Schematic operation of tunnel ventilation in emergency mode: *1*—supply air chamber; *2*—exhaust air chamber.

3. Conclusions

In the routine mode of tunnel ventilation, air flow rate is the same in the ventilation schemes discussed while presser losses are low and differ insignificantly in different design tunnels. For these reasons, it is economically efficient to use the longitudinal ventilation in routine operation. The transverse ventilation in the routine mode is inefficient due to high drag in the air duct, which requires higher blast pressure and fan capacity (respectively, 5.5 and 24.4 times higher than in the longitudinal ventilation). In the emergency mode, it is advisable to use the longitudinal–transverse ventilation with smoke removed via the continuous air channel and fresh air inflow along the escape ways toward both sides from the fire source in the train.

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