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CFD Simulation of Airflow in the Side-Platform Stations

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Abstract. Design of an appropriate ventilation system is one of the main concerns in the construction of subways. In this paper, thermal comforts of side-platform stations are investigated by numerical methods. For the numerical simulation, grids are generated by structured methods and governing equations are discretized by finite volume methods. In the numerical simulation, second order upwind and second order central difference scheme are used to consider the convection and diffusion terms of momentum and energy equations, respectively. Results of this study show that in term of thermal comfort, region next to the hallway and the middle part of the platform is the worst zones of the station. In these zones, air velocity is very low (less than 0.5m/s) and the air temperature reaches to 34°C which is more than its limit (T_{max}≤32°C).

1 Introduction

For the first time, in the 1863 the underground transportation system was used in the England which was used to transport the commercial products and its length was less than 500 meters. By the development of the cities, subways are known as one of the main transportation systems. By the growths of subway systems, generated heat from traction wagons are increased and uncomfortable conditions for the passengers are created. Years later, mechanical ventilation systems are added to the subway lines to create thermal comfort conditions. By definition, an appropriate ventilation system is system which could bring fresh air to the stations and discharge the hot air from exhaust shafts [1].

In 2004, one of complete studies about subway ventilation systems is provided by Ampofo et al in three papers [2-4]. In these papers, different aspects of subway ventilation systems are studied analytically. The first paper [2] reviews published studies about thermal comfort conditions for the subway systems. The second paper [3], investigates the generated heat load in the subways using some mathematical models. And the third paper [4] investigates potential methods of delivering fresh air to underground environment.

Beside these analytical methods, some precious experimental studies about subway ventilation are done in later years by Kim and Kim [5]. In 2007, Kim and Kim are experimentally studied the natural ventilation systems of subway lines. In the natural ventilation systems, the airflow is created by the motion of trains in the station and tunnels. The results of this study show that, both the highest pressure rise and drop occur when the train reaches to its highest speed.

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Nowadays, by development of CFD tools, numerical simulations are used to improve the designed systems. In 2009, effects of train movements on the airflow are investigated by Jia et al[6]. In this study, three dimensional model of a subway is created and airflow in the station is simulated by finite volume methods. In 2010, Yuan-dong and Wei [7] studied the natural ventilation systems of subways by numerical methods. In this study, effect of exhaust shaft on the efficiency of ventilation system is investigated.

In the most of previous studies, natural ventilation systems of subway have been simulated. In current study, mechanical ventilation systems of side-platform stations are simulated and thermal comfort conditions (air velocity and temperature) in different sections of the station and tunnels are predicted. Then, according to the results of numerical simulation, the efficiency of designed ventilation system is investigated.

2 Model and Methodology

2.1 Ventilation System

Ventilation of stations and tunnels by using mid-shafts is one of the most common systems in the subways. In this system, fresh air enters to the station and tunnel through ventilation ducts and shafts. Fresh air absorbs generated heat and hot air is exhausted through mid-shafts. In this system, generated heat for each station (from left mid-tunnel to right mid-tunnel) is computed and then required fresh air will be calculated. In Fig.1 schematics of mechanical ventilation systems by using mid-shaft is shown. In this figure desired domain for station 2 is colored in gray.

2.2 Design Conditions

In Table 1 conditions which are used to design the mechanical ventilation system are shown. These conditions include design temperature and maximum velocity of air in the station and tunnels.

2.3 Three Dimensional Model

In Fig.2 three dimensional model of a typical side-platform station is shown. In this figure, different parts of station and tunnels such as ticket hall, escalators, entrance door and ventilation shafts are shown.

2.4 Grid Generation

Total length of selected side-platform station and tunnels are 150 m and 900m, respectively. For grid generation in this model, the structured method is used. In the structured method, the model is divided into small cubes. In Fig.3 generated grids in the middle section of station is shown. This section crosses through ticket hall and platform.

Table 1. Design conditions of mechanical ventilation system

Design Conditions	Values	Design Conditions	Values
Maximum temperature at station	32°C	Maximum velocity of air in tunnels	7 m/s
Maximum temperature at tunnels	40°C	Temperature of ambient air	36°C
Maximum velocity of air at platform	1 m/s	Temperature of fresh air	26°C

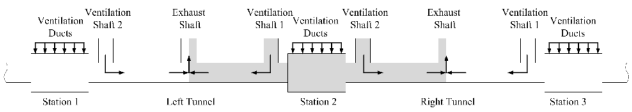

Figure1. Schematic of mechanical ventilation system by using mid-shafts

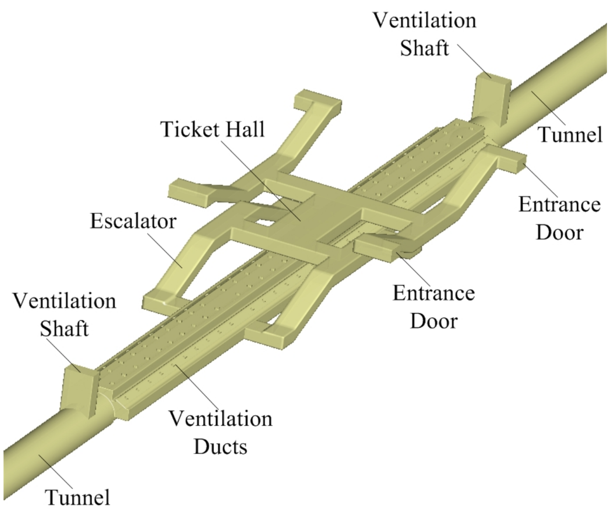

Figure 2. Three dimensional model of a typical side-platform station

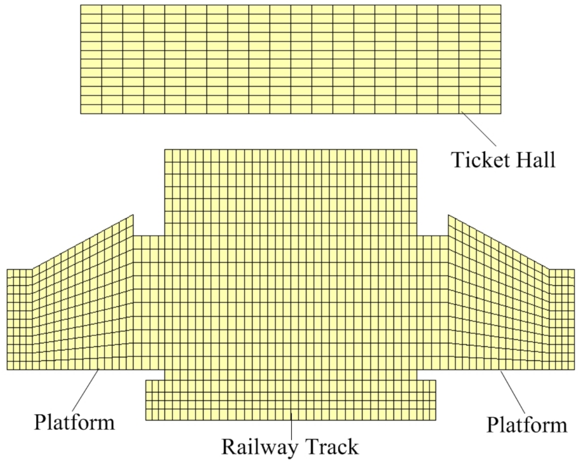

Figure 3. Generated grids in the middle section of side-platform station

2.5 Governing Equations

For prediction of velocity and pressure distribution in the station and tunnels, conservation laws for mass and momentum should be considered. Also, for simulation of temperature field, conservation law for energy should be solved. In Eq.1 to Eq.3 conservation laws for mass, momentum and energy for incompressible steady flows are presented, respectively [8]:

$$\frac{\partial u_i}{\partial x_i} = 0 \tag{1}$$

$$\frac{\partial u_i}{\partial t} + u_j \frac{\partial u_i}{\partial x_j} = -\frac{1}{\rho}\frac{\partial P}{\partial x_i} + \nu \frac{\partial^2 u_i}{\partial x_j \partial x_j} \tag{2}$$

$$\rho \frac{De}{Dt} = -\frac{\partial (Pu_i)}{\partial x_i} + \frac{\partial (u_i \tau_{ji})}{\partial x_j} + \frac{\partial}{\partial x_i}\left(K \frac{\partial T}{\partial x_i}\right) + S_E \tag{3}$$

In these equations, u_i, P, T, e and τ_{ij} are velocity vector, pressure, temperature, internal energy and shear tension tensor. Also, ρ and υ are density and kinematic viscosity of fluid.

2.6 Turbulence Modeling

Approximate Reynolds number of flow in the tunnels of subways is about 10^5 which is calculated based on the hydraulic diameter of tunnel. So, due to high inertia of flow in the station and tunnels, nature of airflow in the subways will be turbulent. In this study, to consider turbulence effects, standard k-ε model is used. In this model, velocity fluctuations are related to the mean velocities by using Boussinesq hypothesis (Eq.4) [9]:

$$-\rho \overline{u_i' u_j'} = \mu_t \left(\frac{\partial \bar{u}_i}{\partial x_j} + \frac{\partial \bar{u}_j}{\partial x_i} \right) - \frac{2}{3}\left(\rho k + \mu_t \frac{\partial \bar{u}_k}{\partial x_k} \right)\delta_{ij} \tag{4}$$

In this equation, $\overline{u_i'}$ and $\overline{u_i}$ are vector of velocity fluctuations and mean velocities. Also μ_t and k are the turbulence viscosity and turbulence kinetic energy.

2.7 Boundary Conditions

The aim of this paper is three dimensional simulation of airflow in the side-platform stations. So, by using formulas in the reference [3] the generated heat for a typical side-platform station is calculated and then required fresh air for mechanical ventilation of station and tunnels are computed. In the Table 2 boundary conditions which are used for the numerical simulation are presented.

Table 2. Boundary conditions of numerical simulation

Boundary Name	Boundary Location	Boundary Condition
Mass Flow Inlet	Ventilation shafts and ducts	$\dot{m}$ = calculted m
Exhaust Fan	Mid-tunnel exhaust shafts	ΔP = according
Pressure Outlet	Entrance doors of station	P = atmospheri
No-Slip Wall	Walls of station and tunnels	$u_i = 0$
Symmetry	End section of tunnels	$\partial / \partial z = 0$

2.8 Source terms

To predict temperature distribution in the station and tunnels, generated heat loads in the subway is considered as an energy source term. In other word, in the first step, the generated heat loads from different parts of subway such as train movement, lighting, passengers and escalator are calculated according to reference [3]. Then, the heat loads are considered as energy source term in different parts of subway.

3 Results

In Fig.4 temperature contours at section with 1.7 m height from the platform is shown. Results show that the temperature of air at the entire parts platform is less than its limitation (T_{max}≤32°C) except the region next to the hallway and the middle part of station. Also results of Fig.4 shows that the fresh air with low temperature (T=26°C) enters to the left and right tunnel through ventilation shafts. The fresh air should absorb the generated heat load and keep the temperature of the station and the tunnels in acceptable range.

In Fig.5 temperature contours at different sections of the right tunnel are shown. Results show that the temperature of tunnel reaches to its maximum at the region next to the mid-shaft. In this area hot and contaminated air will be exhausted to the ambient. Also, detail analysis of temperature contours of Fig.5 show that, due to the braking heat loads, the temperature of tunnel in the lower parts is more than other regions. In other word, friction between train wheels and railway track is the main source of generated heat in the braking process of subway trains. So, the most of heat loads in the braking process will be generated in the region next to the floor. This heat load will make the regions near the floor hotter than other parts.

In Fig.6 and Fig.7 velocity contours at the station and the right tunnel are shown, respectively. It's obvious that high velocity gradient will make the uncomfortable condition in the station. While, results of Fig.6 show that the air is uniformly contributed in entire parts of the station. So, subway passengers could wait in the platform in the thermally suitable condition.

Also results of Fig.7 show that, due to same geometry of tunnel in different sections, the air velocities in different sections of right tunnel are alike. Moreover, results of Fig.6 and Fig.7 show that the maximum velocities of air at platform and tunnels are 1 m/s and 5 m/s which according to the Table 2, these values satisfy the design conditions very well.

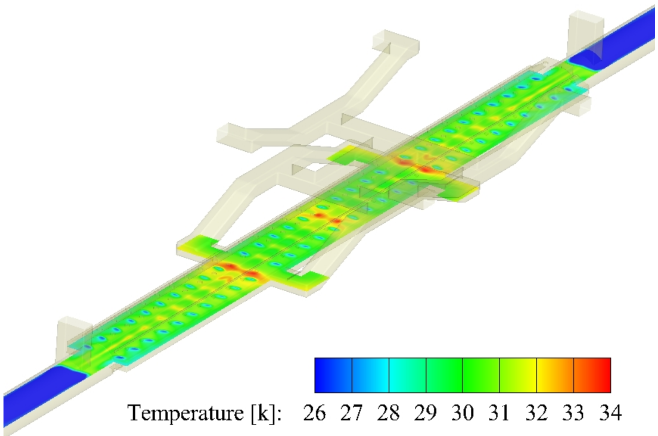

Figure 4. Temperature contours at section with 1.7 m height from the platform

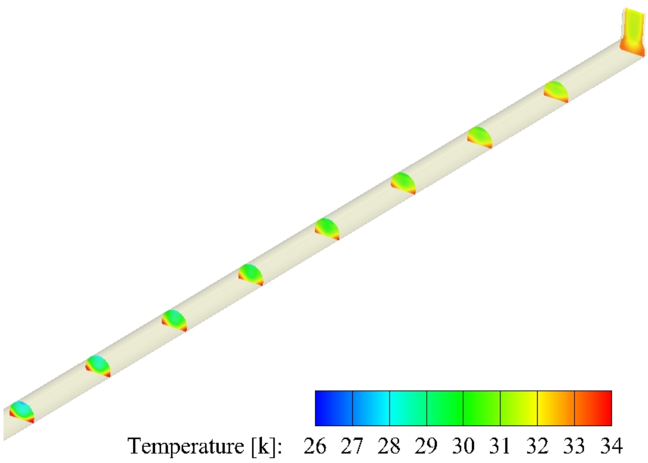

Figure 5. Temperature contours at different sections of the right tunnel

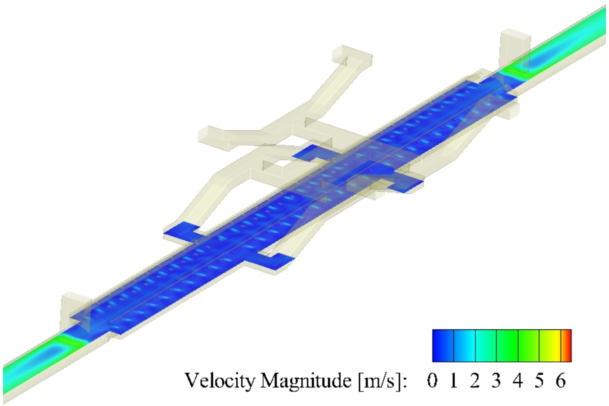

Figure 6. Velocity contours at section with 1.7 m height from the platform

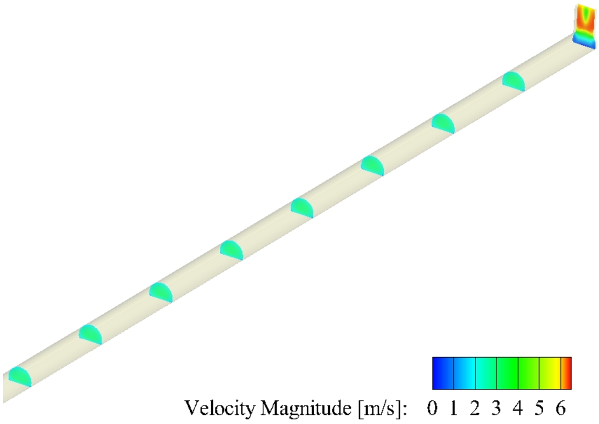

Figure 7. Velocity contours at different sections of the right tunnel

4 Conclusion

In this study, airflow in different parts of a side-platform station is numerically simulated. Results show that the temperature of air at the entire parts platform is less than its limitation (T_{max}≤32°C) except the region next to the hallway and the middle part of station. Also, results of numerical simulation show that the air is uniformly contributed in entire parts of the station and maximum velocity of air in the tunnel is less than its limit (V_{max}≤7m/s). So, designed ventilation system is appropriate and it could keep the temperature and velocity of the station and the tunnels at the thermally comfort conditions.

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