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# Influence of mechanical ventilation-shaft connecting location on subway tunnel ventilation performance

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ABSTRACT

Subways are widely used for public transportation in major cities and require efficient ventilation systems to maintain indoor air quality in the subway tunnel. A subway tunnel was investigated to understand the airflow inside the tunnel, and to improve its ventilation system. The steady three-dimensional airflow in the tunnel was analyzed using ANSYS CFX software to solve Reynolds-averaged Navier–Stokes equations. The ventilation performance in the subway tunnel was investigated with respect to the connecting location of the mechanical ventilation shaft by analyzing mass flow rate through the ventilation-shafts and the airflow in the tunnel. The airflow in the tunnel and the mass flow rate in the shafts were investigated when the guide-vane, the porous zone and the air-curtain were installed in the subway tunnel system. The discharged-air was higher at ventilation-shaft 2 which was connected to the top wall of the tunnel than that of the ventilation-shaft 1 which was connected to the side wall of the tunnel. The numerical results suggested the connecting location of shaft 2 as the optimum connecting location.



## 1. Introduction

Subway tunnels are enclosed spaces and the air quality deteriorates due to air pollutants emitted from moving trains. The air in a subway tunnel is approximately eight times more genotoxic and four times more likely to cause oxidative stress in human lung cells than the air in urban street (Karlsson et al., 2005). Environmental protection and safety are the main reasons for tunnel ventilation (Li and Chow, 2003). The ventilation systems in subway tunnels, including train-induced airflow, need investigation. Experimental and numerical studies have been performed to analyze the unsteady three-dimensional flow in a subway tunnel with a single track (Modic, 2003; Ogawa and Fujii, 1997). Train-induced airflow was studied numerically and experimentally for tunnels with more than one track. Experimental studies of the effects of moving vehicles on tunnel ventilation were performed for the cases of two trains moving in the same and opposite directions (Chen et al., 1998). The airflow is not sufficient to push the pollutant-air out of the tunnel when two trains run in opposite directions. Numerical simulations have been performed to analyze the airflow in a subway twin-track tunnel (Li et al., 2006; Waymel et al., 2006). Subway tunnel and ventilation systems were built many years ago. However, high performance trains generate an amount of heat that exceeds the ability of piston-effect ventilation to remove it from the subway tunnel. Adequate subway ventilation is needed to maintain indoor air quality (Song et al., 2008). Airflow characteristics of the guide-vane and the air-curtain installations in a tunnel were discussed (Fukutomi and Nakamura, 2005; Guyonnaud et al., 2000).

Model subway tunnel was constructed to investigate the airflow inside the tunnel and to improve the ventilation performance in the tunnel. The objective of this study is to improve ventilation performance with respect to the connecting location of the mechanical ventilation-shaft by analyzing the mass flow through the ventilation-shaft and the airflow in the tunnel. The airflow in the tunnel and the mass flow in the shafts with the guide-vane, train-wind, porous zone, and air-curtain installations were examined using ANSYS CFX software by solving Reynolds-averaged Navier–Stokes equations (ANSYS CFX, 2009).

## 2. Numerical procedures

### 2.1. Analysis: computational tools and turbulence model

ANSYS CFX software consists of Workbench, CFX-Pre, CFX-Solver, and CFX-Post. ANSYS Workbench provides the geometry and modifies the geometry read-through data formats. Standard two-equation turbulence models often fail to predict the onset and the amount of flow separation under adverse pressure gradient

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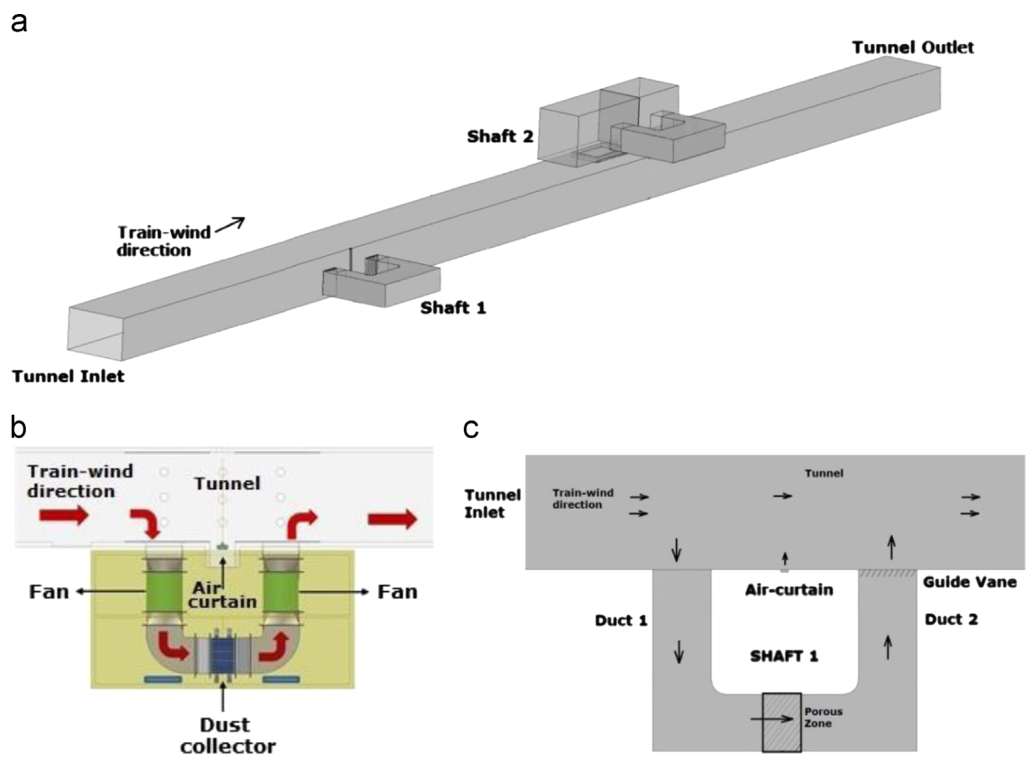


**Fig. 1.** Geometry of subway tunnel. (a) 3D view of the tunnel, (b) top view of the shaft and (c) installed locations of the guide-vane, the porous zone, and the air-curtain (top view).

conditions, whereas the $k$–$\omega$-based Shear Stress Transport model was designed to give highly accurate predictions of the onset and the amount of flow separation under adverse pressure gradients by the inclusion of transport effects into the formulation of the eddy viscosity (Menter, 1994). The time derivative terms can be discretized for accurate unsteady computations. The choice of the turbulence model depends on considerations such as the flow physics including massive flow separations, the established practice for a specific class of problem, the level of accuracy required, the available computational resources, and the amount of computing time available for the simulation. The computational results were obtained using parallel PCs (cluster system: Core 2, Quad 2) running the Linux operating system.

**Table 1**
Grid validation for the model subway tunnel with two shafts (refer to Fig. 1(a)).

| Grid elements (million) | Mass flow rate (kg/s) | |
|---|---|---|
| | Shaft 1 | Shaft 2 |
| 2 | 10.8525 | 11.5125 |
| 2.3 | 11.3555 | 12.0655 |
| 3.1 | 11.8895 | 12.5695 |
| 3.5 | 11.9025 | 12.6325 |
| 5.2 | 11.9111 | 12.6513 |
| 5.8 | 11.9137 | 12.6537 |
| 6.1 | 11.9133 | 12.6533 |

### 2.2. Numerical model of the model subway tunnel

A numerical model was computed without the train runs. The subway tunnel under consideration was straight and has no stations, as shown in Fig. 1. It is 54 m long, 1.65 m high and 2.5 m wide. The model tunnel was constructed using one-quarter scale with respect to a real subway tunnel. The subway tunnel had two mechanical ventilation shafts. Shaft 1 was installed 18 m from the tunnel inlet and shaft 2 was 30 m from the tunnel inlet. Shaft 1 was connected to the side of the subway tunnel. Shaft 2 was connected at the top of the subway tunnel. The mechanical ventilation shafts had two ducts each. The air was discharged through duct 1 of each shaft, and passes a dust collector installed in the middle of the shaft as shown in Fig. 1(b). The discharged air passes the dust collector and enters into the tunnel through duct 2 of each ventilation shaft. The numerical model of the subway tunnel is based on the fluid domain. An air-curtain was installed between ducts 1 and 2 of the shaft of the subway tunnel (Gupta et al., 2006). The thickness of the air-curtain was fixed to 0.1 m and the lengths of the air-curtain were 1.65 m and 2.5 m, respectively. The air-jet of the air-curtain had some zones of depending on the height of the air-curtain installing location and the velocity of the air-curtain (Guyonnaud et al., 2000). Fig. 1(b) shows the installed locations of the air-curtain, the porous zone, and the guide-vane. The guide-vane was installed at the end of duct 2 of the shafts. The installation angles of the guide-vane were 30°, 45°, and 60°. Each shaft had two ducts: one to discharge and the other to supply the airflow. The porous zone is a material consisting of a solid structure with an interconnected void on the microscopic scale, and flow characteristics such as velocity and pressure are irregular (Nield and Bejan, 1992). The structure of the porous zone has a porosity of 70%, which means that 70% of the volume is available for airflow and the other 30% is occupied by the solid material that comprises the structure.

### 2.3. Computational grid validation

The computational grid of the tunnel flow field was generated by unstructured tetrahedral grid. The grid was distributed along three axes. A grid validation study was performed to ensure that the computed quantities would properly converge. Table 1 shows the results of the validation study. The validations of the numerical method were made for the computational domain. The numbers of elements of the tetrahedral mesh were between 1.9 million and 6.1 million. The airflow passing through the shaft was observed in the tunnel. The validation results indicated that the proper grid size for