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A COMPUTATIONAL ANALYSIS OF AIRFLOW IN MECHANICAL SHAFT OF THE SUBWAY TUNNEL TO APPLY THE DEVELOPED VENTILATION SYSTEM

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***Abstract*—The steady three-dimensional airflow in subway tunnel was analyzed using ANSYS CFX software and by solving Reynolds-averaged Navier-Stokes equations. A mechanical shaft of existing Seoul subway tunnel was analyzed to apply the developed ventilation system to the subway tunnel. Emergency duct between the ducts of the mechanical shaft was used to connect ducts and install the precipitator. The ducts of the mechanical shaft were connected with two ways such as Duct 1&Duct 2, and Duct 1&Emergency duct. The mass flow rate was higher at the shaft in Duct 1&Emergency duct connection than Duct 1&Duct 2 connection. The guide vanes were installed in the shafts before the electric precipitator to obtain uniform flow. The uniform flow helps to increase the performance of the precipitator. The developed ventilation system was applied to the existing subway tunnel by connecting ducts and installing the guide vanes.**

***Index Terms*—indoor air quality, guide vane, mechanical shaft, twin-track subway tunnel, train-induced flow.**

I. INTRODUCTION

Subway tunnels and ventilation systems were built many years ago. The tunnels are enclosed spaces and the air quality deteriorates due to air pollutants emitted from moving trains. High performance trains generate an amount of heat that exceeds the ability of piston-effect ventilation to remove it from the subway tunnel. Proper subway ventilation is needed to maintain indoor air quality. Platform Screen Doors (PSDs) improve the platform environment; however, may degrade the air quality in subway tunnel. Particulate matter (PM) level is higher in the tunnel than that in the subway platform. The airborne radon levels in the subway cabins were increased by 53% after PSD installation in the subway station [1]. Radon is a colorless, odorless and tasteless gas produced by radioactive decay of uranium and thorium and its progenies have health hazards for human.

Experimental and numerical studies were performed to analyze the unsteady three-dimensional flow field in subway tunnel with single-track [2, 3]. The train-induced airflow was studied both numerically and experimentally when tunnel had more than one track. Experimental studies investigating the effects of moving vehicles on the tunnel ventilation were performed when two trains had the same and the opposite directions [4]. The airflow was not sufficient to push vitiated airflow out of a tunnel when two trains run in opposite directions. Numerical simulations were performed to analyze the airflow in the subway twin-track tunnel [5, 6]. Adequate subway ventilation system was necessary to maintain the Indoor Air Quality (IAQ) [7]. The station IAQ becomes worse due to the high concentration of fine dusts from the tunnels which were transported into the subway platform by trains. Therefore, proper ventilation system was needed to maintain IAQ in subway tunnel [8].

The objective of this study was to apply the developed ventilation system to the existing subway tunnel by connecting the ducts of the mechanical shaft. The airflow in the existing subway tunnel was analyzed using ANSYS CFX software by solving Reynolds-averaged Navier-Stokes equations [9].

II. COMPUTATIONAL PROCEDURE

A. The turbulence model and the boundary conditions for the computational domain

Standard two-equation turbulence models often fail to predict the onset and the amount of flow separation under adverse pressure-gradient conditions, while the k-ω based Shear Stress Transport model was designed to make 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 [11]. The choice of the turbulence model depends on considerations such as the flow physics including massive flow separations, established practice of a specific class of problem, level of accuracy required, available computational resources, and amount of computing time available for the simulation. The k-ω based Shear Stress Transport model had similar governing equations as to the standard k-ω model of Wilcox.

A numerical computation was performed without the train runs. The working fluid was air at 25 °C under atmospheric pressure. The adiabatic wall boundary condition was used for the tunnel walls. All walls were treated as viscous adiabatic surfaces with no-slip velocity conditions. The opening condition was imposed at the outlet of the subway model tunnel for flow analysis with a train-wind. The pressure boundary conditions were applied to the ducts of the shafts. Air-curtain velocity of 25 m/s was applied at the air-curtain inlet. The flow field was analyzed in the steady state. The train-wind velocity was prescribed at the tunnel inlet.

III. RESULTS AND DISCUSSIONS

A. The developed mechanical shaft of the real tunnel

The mechanical shaft has important role in the developed ventilation system. The mechanical shaft of the real tunnel was investigated to apply the developed ventilation system in the real tunnel. The real tunnel which is 100 m long with one the mechanical shaft was chosen as the computational domain without the train run and the precipitator. The train-wind was applied at the track 1 and same boundary conditions were applied to the computational domain. The mechanical shaft of the real tunnel was investigated numerically. The mechanical shaft was to discharge the dusty air and to supply the clean air. Figure 1 shows two ways of the connecting ducts to apply the developed ventilation system in the tunnel. The existing mechanical shaft has three ducts such as Duct 1, Emergency Duct and Duct 2. The emergency duct was the duct between Duct 1 and Duct 2 and was used in the developed ventilation system. There are two ways of connecting Duct1&Duct 2 and Duct 1&Emergency Duct. The dusty air entered through Duct 1, passed through the electric precipitator and the cleaned-air from the precipitator entered into the tunnel. The connected ducts were computed with the real subway tunnel. The connections were evaluated by the mass flow rate which passed through the mechanical shaft. The axial-flow fans were installed in the ducts of the mechanical shafts. The computations showed the velocity vector distribution and the mass flow rates in the mechanical shafts. The velocity vector distributions in the shaft were shown in Figure 2. The mass flow rate was measured at the precipitator installing location. The mass flow rates were 100.058 kg/s in Duct 1 & Emergency Duct connection and 93.89kg/s in Duct 1 & Duct 2 connection. Duct 1&Emergency Duct connection were selected for the further computations.

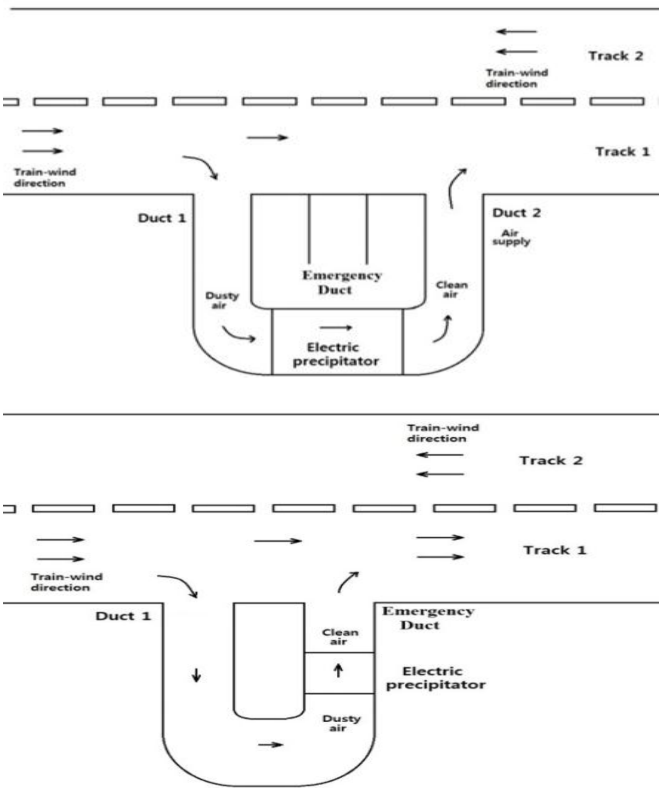


Figure 1. The schematic view of the shafts connections as a) Duct 1&Duct 2 and b) Duct 1&Emergency Duct

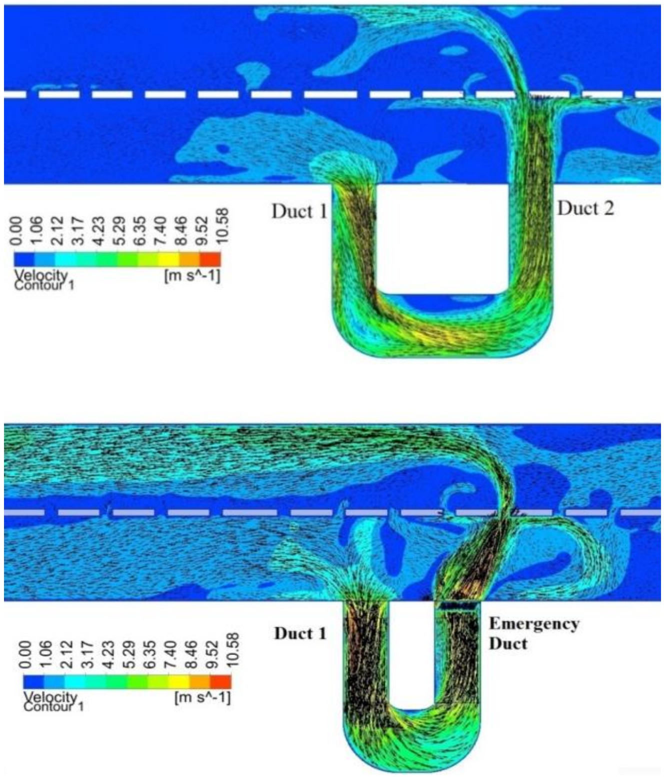


Figure 2. The velocity distributions in the tunnel and the mechanical shafts connected as a) Duct 1&Duct 2 and b) Duct 1&Emergency Duct

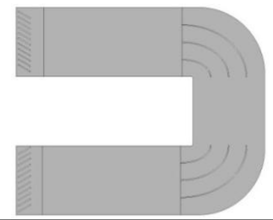
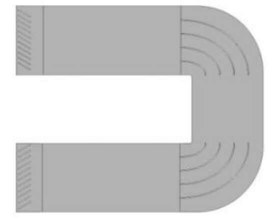
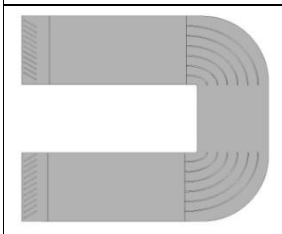
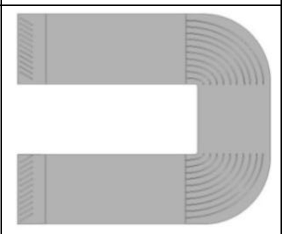
B. The installing the guide vane in the mechanical shaft before the electric precipitator

The precipitators were used to reduce the amounts of pollutant in exhaust stream. They have a grid or baffle filter to remove large particulates from the exhaust air stream. The efficiency of the precipitator is affected significantly by the airflow velocity. The air velocity at the precipitator was controlled by the guide vanes for high efficiency. The precipitator was installed in the duct of the ventilation shaft. The real subway tunnel was investigated with guide vane installation and the train-wind. The guide vanes were installed in the mechanical shaft to obtain uniform flow before the electric precipitator as given in Table 1.

The airflow entered into Duct 1 and strongly rotated while the airflow passed the fan of Duct 1. The reverse airflow was formed in the center of Duct1 and the airflow moved forward passing by the installed guide vanes. The velocity of the airflow was high at the wall of the mechanical shaft. The high velocity was observed at the wall in all cases. The airflow becomes homogeneous and the backflow phenomenon was prevented in the duct when the number of the guide vane was increased. Figure 3 shows the measured areas after the guide vane, the just before the electric precipitator

The airflow was entered and rotated strongly while passing the suction fan in Duct 1. Figure 4 shows the velocity distributions in the mechanical shaft when the guide vane was installed both sides of the shaft middle. The rotating airflow stabilized primarily while passing the first guide vane installation and meets the second guide vane installation. The airflow after the second guide vane was relatively uniform. The guide vanes reduce the speed of the airflow and prevent the rotational airflow in the middle of the shaft. The homogenization of the airflow was obtained when the guide vanes were installed at both sides. However, the low average velocity at the areas which are close to the wall reduces the average velocity in the cross-section. The average velocity was measured at the A-A cut view and it is high at the center parts of the shaft. Table 2 presents the average velocities at the guide vane areas. The average velocity of the guide vane areas was relatively similar as number of the guide vane increases. The averages velocity of the areas is lower when three guide vanes were installed. Homogenization of the airflow in the shaft was much better in both side guide vane installation than one side guide vane installation. However, the cost of installation increases as the number of the guide vane increases. The proper guide vane installation was three guide vanes at both sides of the mechanical shaft according to the computational results.

Table 1. The guide vane installation in the middle of the shaft (top view)

	
2 side Guide Vane 3	2 side Guide Vane 4
	
2 side Guide Vane 6	2 side Guide Vane 10

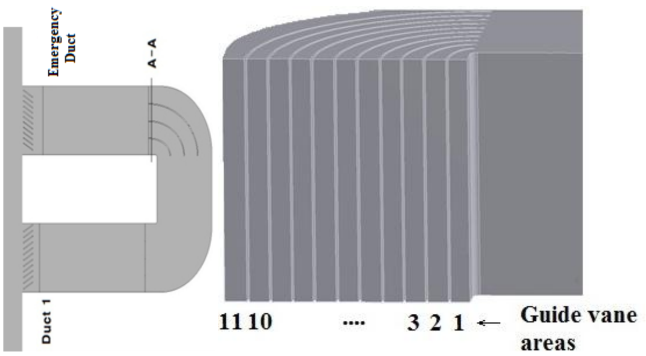
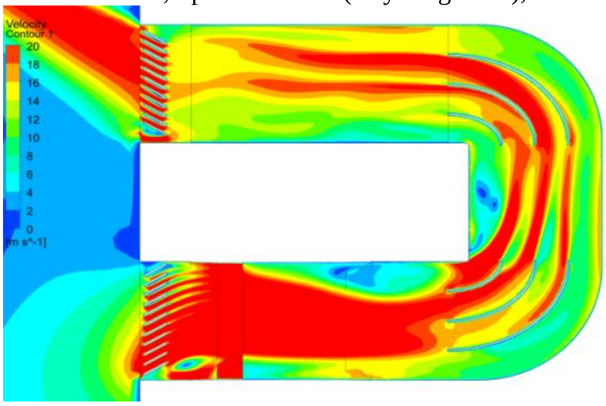
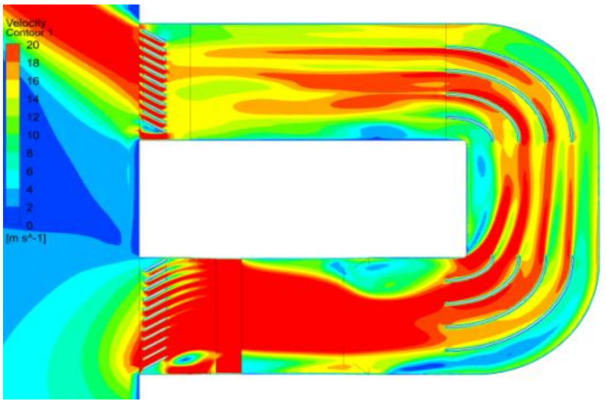


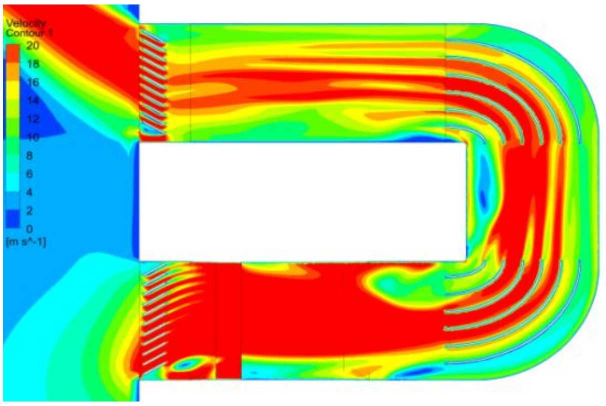
Figure 3. The guide vane (cut view of the guide vane) a) location of A-A cut and b) the areas



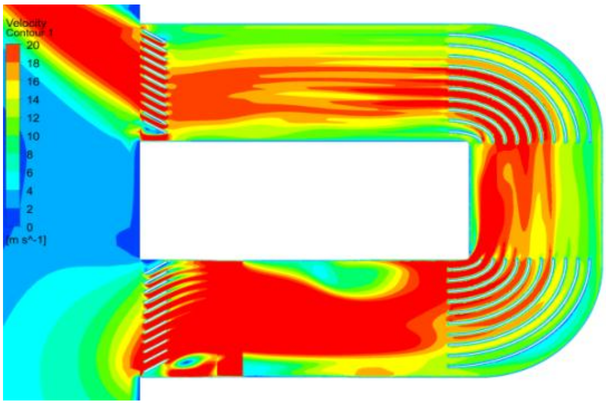
Guide Vane 3



Guide Vane 4



Guide Vane 6



Guide Vane 10

Figure 4. The velocity contour distributions for two side the guide vane installations in the shaft

Guide vane areas (A-A cut)	Without guide vane	The numbers of the installed guide vane			
		3	4	6	10
1	14.4	8.157	8.63	8.60	6.31
2		20.1	10.62	7.12	8.16
3		13.19	22.68	11.0	9.18
4		11.18	13.74	25.54	20.24
5			11.61	19.34	25.31
6				11.3	13.79
7				11.08	14.02
8					13.37
9					16.11
10					11.35
11					12.86
Average velocity of the areas	14.4	13.23	13.46	13.42	13.7

Table 2. The average velocity distributions at the guide vane areas (when the guide vane was installed both sides of the shaft)

I. CONCLUSION

An air quality in subway tunnel deteriorated due to air pollutants emitted from the trains. Installing dust removing systems, electric precipitator inside the tunnel was impossible and fire problems might arise in case of the installation. The objective of research was to apply the developed ventilation system to the existing subway tunnel. The ANSYS CFX software was used to perform the unsteady computations of the flowfield in the subway tunnel by solving Reynolds-averaged Navier-Stokes equations. The ventilation performance was investigated by observing the mass flow rate through the mechanical shafts in the existing subway tunnel. The ducts of the mechanical shaft of the existing subway tunnel were connected to analyze the ventilation system in the tunnel. Existing emergency duct between the ducts of the mechanical shaft was used. The mass flow rate was higher at the mechanical shaft in Duct 1&Emergency Duct connection than Duct 1&Duct 2 connection. The guide vanes were installed in the mechanical shaft before the electric precipitator to obtain uniform flow. Three guide vane installations at the both sides of the shaft gives required results due to the computations.

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