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Calculation of CO Behavior in the Platform for Deeply Underground Subway Station with Different Fire Strengths

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Abstract: Effect of different fire strengths on the smoke distribution in the subway station is investigated. Shin-Gum-Ho station (line #5) in Seoul is selected as a case study for variation of CO (carbon monoxide) distribution caused by the fire in the platform. The ventilation in the station is set to be an air supply mod in the lobby and an air exhaustion mod in the platform. One-side main tunnel ventilation (7,000 m^3/min) is applied to operate in the tunnel. The fire is assumed to break out in the middle of train parked in the platform tunnel. Two kinds of fire strength are used. One is 10 MW and the other is 20 MW. Ventilation diffusers in the station are modeled as 317 square shapes & four rectangular shapes in the lobby and platform. The total of 7.5 million grids is generated and whole domain is divided to 22 blocks for parallel computation. Large eddy simulation method is applied to solve the momentum equation. The behavior of CO is calculated according to different fire strengths and compared with each other.

Key words: Carbon monoxide, subway station, fire strength, main tunnel ventilation, LES.

1. Introduction

Korea government has steadily supported the fire-accident prevention research since fire disaster in Daegu subway station which occurred in 2003. It has enforced to establish the several laws for fire safety standard in railway system in Korea. However, the fire-safety measures for subway station and subway tunnel have not been much arranged yet in Korea.

Some researchers have studied the fire-driven flow analysis in tunnel. Hwang and Edwards [1] studied the hot stratified flow and ventilated flow in tunnel. Hwang and Wargo [2] showed the thermally generated reverse stratified layers in fire tunnel using experimental method. Jang, et al. [3] studied the back-layer flow phenomena in the straight tunnel using LES (large eddy simulation) and RANS (Reynolds-averaged Navier-Stokes). They compared the simulated results with experimental data and showed that LES produced better results than RANS. Fletcher, et al. [4] experimentally investigated the tunnel fire using a pool fire. They also calculated the same fire-driven flow as their experiments using k-ε model and compared the results. Gao, et al. [5] theoretically studied the tunnel fire flow which was experimentally done by Fletcher, et al. [4]. They employed LES method and compared the results with experimental data. Jang, et al. [6] experimentally investigated the ordinary and emergency ventilation system in deeply underground subway station to study the exact ventilation capacity of subway station. Jang, et al. [7] analyzed the smoke distribution in the subway station with various main tunnel ventilations. They showed the smoke density was reduced in the platform of station with main tunnel ventilation.

Effect of fire strength on the smoke distribution in the subway station is investigated in this research. Shin-Gum-Ho subway station (depth: 46 m), which is the same station as studied by Jang, et al. [7], is

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Table 1 Case study for different fire strengths.

Cases	Descriptions	Tunnel ventilation capacity	Fire strength
1	No main tunnel ventilation	0	10 MW
2	One side exhaustion	-7,000 m^3/min	10 MW
3	No main tunnel ventilation	0	20 MW
4	One side exhaustion	-7,000 m^3/min	20 MW

selected as a case study for variation of CO (carbon monoxide) distribution caused by the different fire strengths. The CO density is most concerned when fire break out in subway station.

Fire is assumed to break out in the middle of train which is parked in platform. The two kinds of fire strength are used. One is 10 MW and the other is 20 MW. Currently, ventilation operation mode in Shin-Gum-Ho station is set up as a full exhaustion mode in the platform in case of platform-fire emergency. Furthermore, main tunnel ventilation is also applied to be operated as prescribed in Table 1 for helping of smoke exhaustion in platform. The LES method in FDS (fire dynamics simulator) code is used to simulate the fire-driven flow in this station. Parallel computation is employed to reduce the calculation time.

2. Modeling of Station

The total number of floors in Shin-Gum-Ho station is 8. The first and second floor undergrounds are lobby and the eighth floor underground is platform. Fig. 1 shows the overall view and ventilation

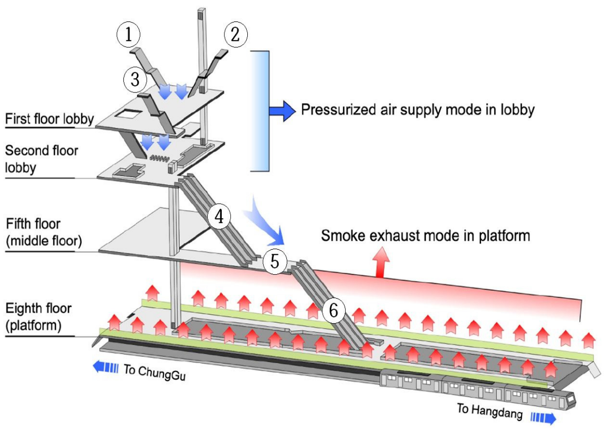


Fig. 1 Ventilation fan modes in Shin-Gum-Ho station for emergency state.

Table 2 Ventilation rate in the lobby and platform of Shin-Gum-Ho station for emergency state.

Case		Flow rate (m^3/h)	
		Supply air	Exhaustion
Emergency state	Lobby	42,126	-22,561
	Platform	-	-276,094

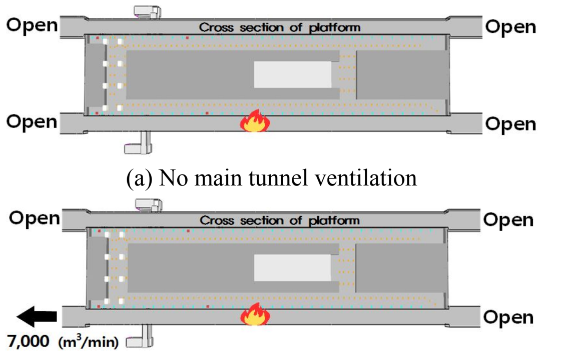


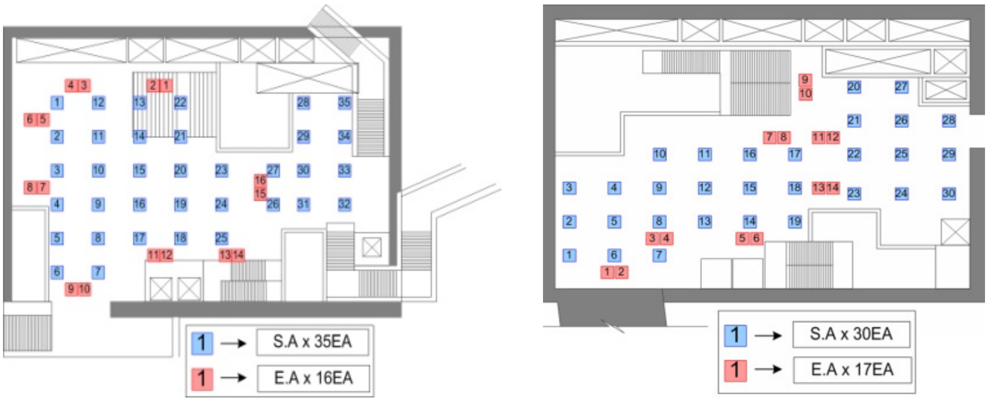
Fig. 2 Application of main tunnel ventilation.

condition for emergency state in Shin-Gum-Ho station. The pressurized air is supplied in the first and second floor lobby. The contaminated air by smoke in the platform is exhausted through the ventilation. Table 2 [6] shows the ventilation rate in the lobby and platform of Shin-Gum-Ho station for emergency state.

Fig. 2 shows the conditions for main tunnel ventilation and capacity which is well described in Table 1. Fig. 3 shows the ventilation distribution in the first and second floor underground. Ventilation diffusers are modeled as 95 square shapes of 0.6 m (x) × 0.6 m (y) in the lobby (Fig. 3) and as 222 square shapes of 0.6 m (x) × 0.6 m (y) and four large rectangular shapes of 1.2 m (x) × 0.8 m (y) in the platform (Fig. 4).

3. Governing Equation and Numerical Methods

The FDS code solves numerically a form of Navier-Stokes equations, and the core algorithm for momentum equations is an explicit predictor-corrector scheme that uses second order accurate finite-difference approximation. The flow variables are updated in time using an explicit second-order Runge-Kutta scheme. Turbulence is treated by means of the Smagorinsky form of LES.



(a) (b)

Fig. 3 Diffuser arrangement of (a) the first floor underground and (b) the second floor underground.

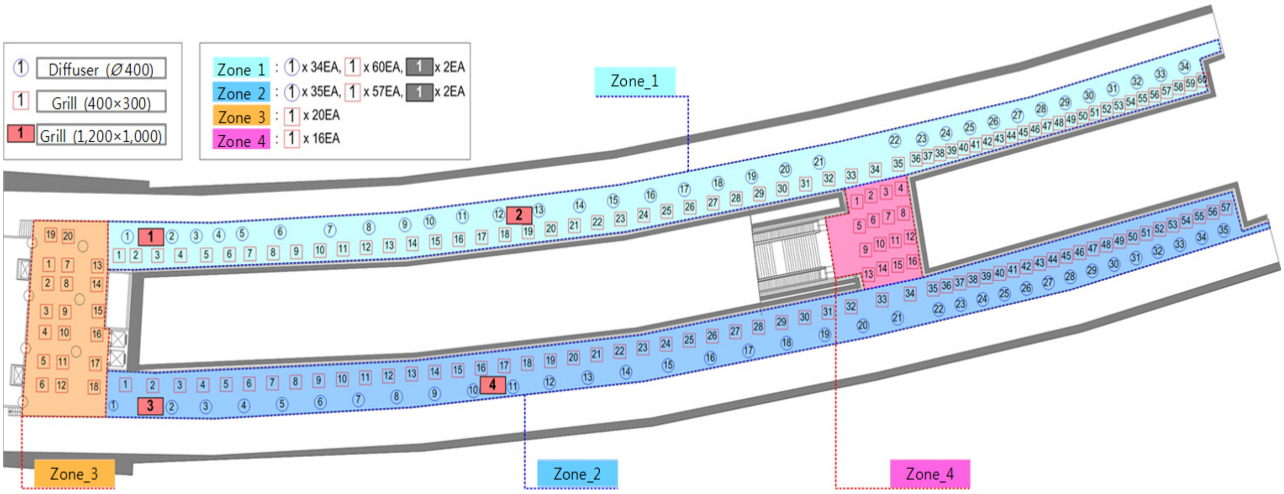


Fig. 4 Diffuser arrangement in the platform of Shin-Gum-Ho station.

The governing equations [8] for LES in FDS are as follows:

$$\frac{D\overline{U_i}}{Dt} = -\frac{1}{\rho}\frac{\partial \overline{P}}{\partial x_i} + \frac{\partial}{\partial x_j}\left\{ \nu\left(\frac{\partial \overline{U_i}}{\partial x_j} + \frac{\partial \overline{U_j}}{\partial x_i}\right) - \tau_{ij} \right\} \quad (1)$$

$$\tau_{ij} = \overline{U_i U_j} - \overline{U_i}\,\overline{U_j} \quad (2)$$

$$\tau_{ij} - \frac{1}{3}\delta_{ij}\tau_{kk} = -2\nu_t \overline{S_{ij}} \quad (3)$$

$$\overline{S_{ij}} = \frac{1}{2}\left(\frac{\partial \overline{U_i}}{\partial x_j} + \frac{\partial \overline{U_j}}{\partial x_i}\right) \quad (4)$$

In Eqs. (1)-(4), ρ, $\overline{P}$, $\overline{U_i}$, τ_{ij}, $\overline{S_{ij}}$ and ν_t, respectively denotes density, mean static pressure, mean velocity, turbulent fluctuation tensor, strain rate tensor and turbulent viscosity.

Where ν_t should be modeled, Smagorinsky model [9] is employed in FDS code.

$$\nu_t = (C_s \overline{\Delta})^2 \left|\overline{S}\right| \quad (5)$$

$$\left|\overline{S}\right| = (2S_{ij}S_{ij})^{1/2} \quad (6)$$

$$\overline{\Delta} = (\Delta x \Delta y \Delta z)^{1/3} \quad (7)$$

where, C_s is an empirical constant and is 0.2. In Eq. (7), Δx, Δy, Δz denote grid distances in x, y, z coordinates, respectively.

The grid size is then selected to be 0.2 m and the total grid numbers are 7.5 million (Fig. 5). The whole domain is divided to 22 blocks and computed on 10 CPU (central processing unit) in parallel using MPI (message passing interface).

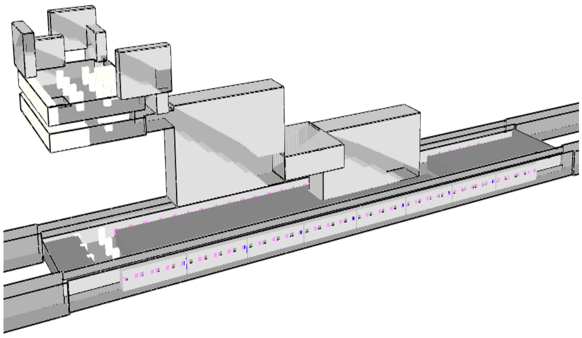
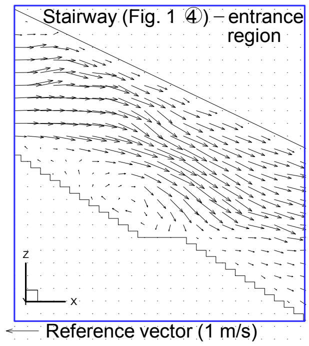


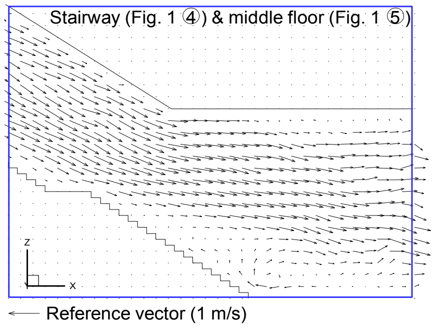
Fig. 5 Grid modeling for Shin-Gum-Ho subway station.

4. Results and Discussion

Fig. 6 shows velocity vectors (maximum ≈ 0.97 m/s) in the entrance region (④ in Fig. 1) and middle floor region (⑤ in Fig. 1) of the stairway for fire strength 10 MW without main tunnel ventilation at 1,300-1,500 s. The fresh air in the lobby is moving down through the stairway to the platform. It is observed that, the hot smoke air due to the fire in the platform cannot overcome the incoming flow from the lobby. Therefore, CO cannot move up to the lobby with fire strength 10 MW in the platform. Fig. 7 shows velocity vectors in the same locations as in Fig. 6 with main tunnel ventilation (7,000 m³/min). The velocity vectors (maximum ≈ 2.2 m/s) in the stairway become stronger than without main tunnel ventilation. The reason is that, the pressure in the platform is decreased due to the operation of tunnel ventilation. Large vortices are found in the stairway and its size is about 1.5 m in height. Fig 8 shows velocity vectors (maximum ≈ 1.12 m/s) in the same locations as in Fig. 6 for fire strength 20 MW without main tunnel ventilation. The magnitude of velocity is similar with case of 10 MW. The back flow is slightly generated near the top of middle floor because of buoyancy force of smoke caused by stronger fire strength in the platform. Fig 9 shows velocity vectors (maximum ≈ 2.3 m/s) in the same locations as in Fig. 6 with fire strength 20 MW and with main tunnel ventilation (7,000 m³/min). The magnitude of velocity is increased compared with no main tunnel ventilation, however, is similar with Case 2.

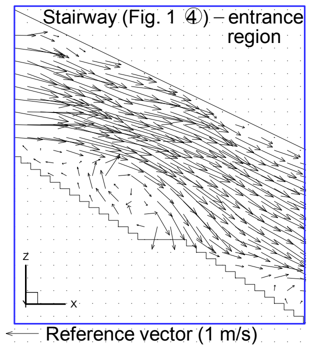


(a)



(b)

Fig. 6 Velocity vectors (every other vector) in the stairway: (a) entrance region and (b) middle floor region for 10 MW without tunnel ventilation.



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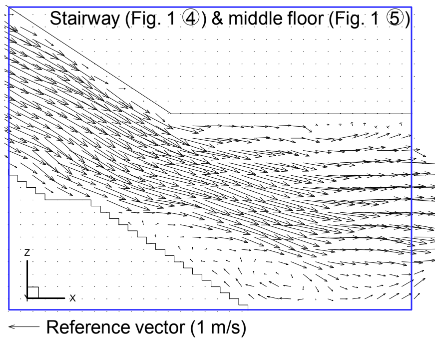
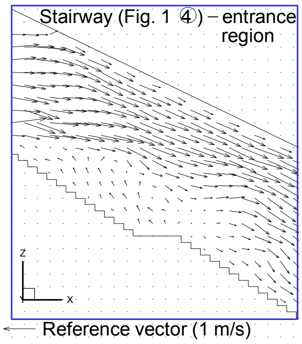


(b)

Fig. 7 Velocity vectors (every other vector) in the stairway: (a) entrance region and (b) middle floor region for 10 MW with tunnel ventilation.



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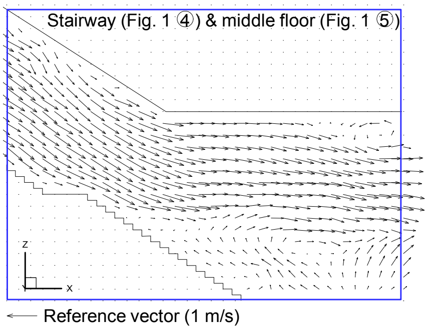
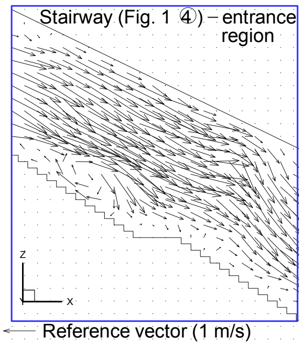
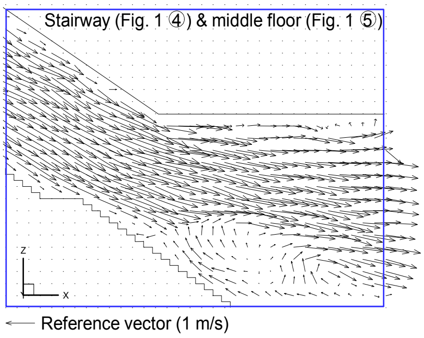


(b)

Fig. 8 Velocity vectors (every other vector) in the stairway: (a) entrance region and (b) middle floor region for 20 MW without tunnel ventilation.



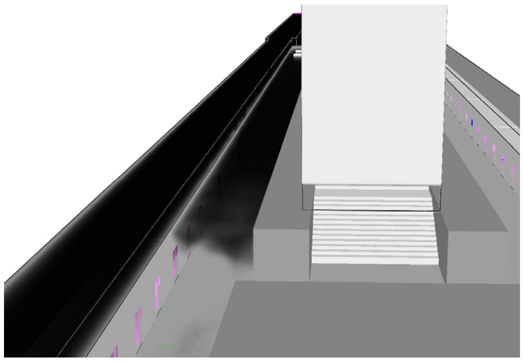
(a)



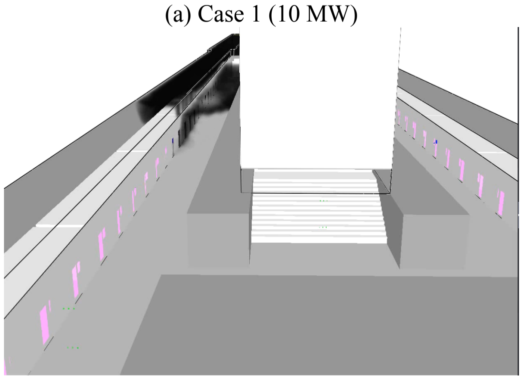
(b)

Fig. 9 Velocity vectors (every other vector) in the stairway: (a) entrance region and (b) middle floor region for 20 MW with tunnel ventilation.

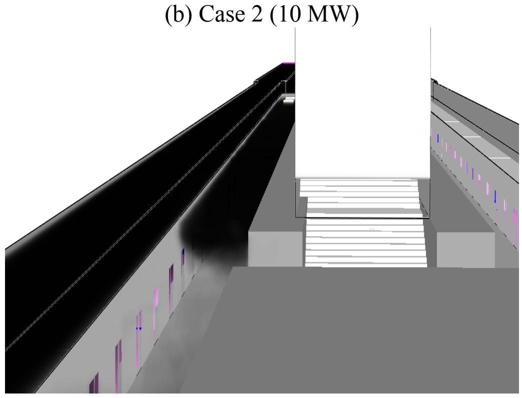
Fig. 10 shows the soot (smoke) distribution in the platform. Large amounts of soot occupy the platform without main tunnel ventilation (Figs. 10a and 10c). In



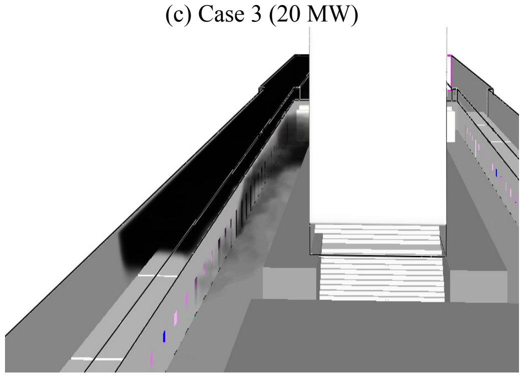
(a) Case 1 (10 MW)



(b) Case 2 (10 MW)

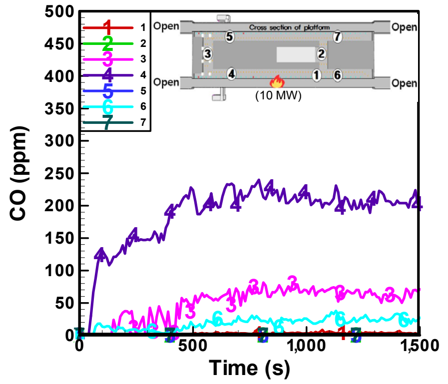


(c) Case 3 (20 MW)

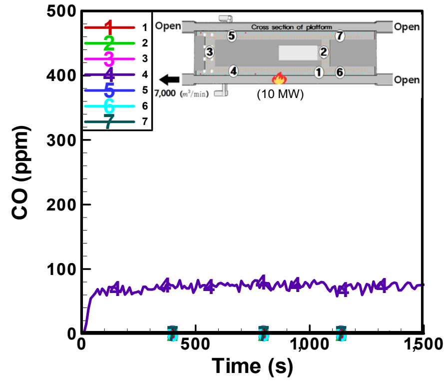


(d) Case 4 (20 MW)

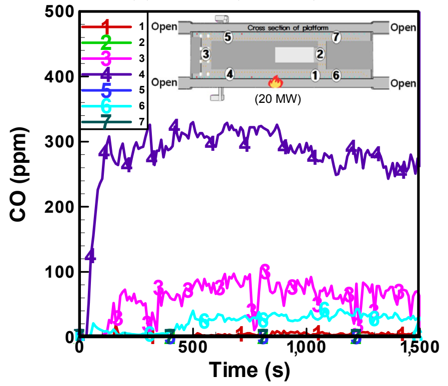
Fig. 10 Soot distributions in the platform with different fire strengths.



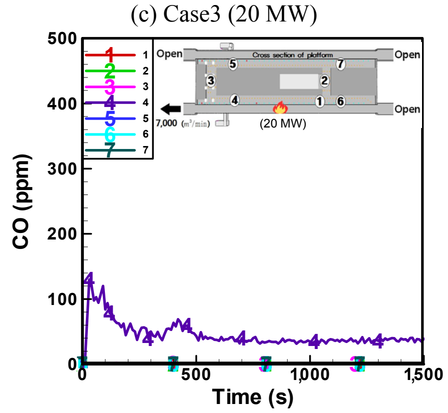
(a) Case 1 (10 MW)



(b) Case 2 (10 MW)



(c) Case3 (20 MW)



(d) Case 4 (20 MW)

Fig. 11 Calculated CO in the platform with different fire strengths.

case of operation of main tunnel ventilation, the smoke is not much propagated into the platform due to the tunnel ventilation (Figs. 10c and 10d). However, the soot is a little more propagated into the platform with 20 MW than with 10 MW. It is clearly seen that, the main tunnel ventilation plays an important role to eliminate the smoke in the platform and help the passenger escape to safety zone.

Fig. 11 shows CO distribution in the platform with different fire strengths. The CO densities are calculated at seven points in the platform. The soot density is 50% increased with stronger fire strength 20 MW in the platform. With main tunnel ventilation, however, the soot is decreased by 65%-80%. Interesting thing is the soot density has become steady state after 1,000 s since fire occurrence in both 10 MW and 20 MW case. It seems that, the steady state circumstance is dependent on total ventilation capacity in the station and tunnel.

4. Conclusions and Summary

CO distributions generated by the fire in the platform with different fire strengths in the subway station are calculated. The Shin-Gum-Ho station in the Seoul is modeled. The smoke flow due to the fire is analyzed and then the distribution of CO is calculated. LES and parallel computing is employed to simulate the fire-driven flow in the whole station.

The flow in the stairway and middle floor goes down to the platform due to the low pressure caused by strong ceiling ventilation in the platform. Main tunnel ventilation induces much increased going-down flow in the stairway. With fire strength 10 MW in the platform, the velocity in the stairway is about 0.9 m/s or less. With fire strength 20 MW in the platform, the velocity in the stairway is about 1.1 m/s which is similar with 10 MW case. The back flow is slightly generated near the top of middle floor because of buoyancy force with fire strength 20 MW. The magnitude of velocity in the stairway with main tunnel ventilation is two times larger than without tunnel ventilation. The soot density is 50% increased with stronger fire strength 20 MW in the platform. With main tunnel ventilation, however, the soot is decreased by 65%-80%.

Acknowledgment

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