Simulation of Smoke Control in a Subway Station Fire

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Abstract

The fire at a Daegu subway station in 2003 showed importance of smoke control, where the ventilation system apparently failed to remove smoke. In the present study, the NIST Fire Dynamics Simulator is utilized to investigate smoke control in a subway station. The computational domain, 10 m x 3 m floor and 5.4 m high, consists of a part of the platform, a stairway and a corridor. The fire size is assumed to be 200 kW. Distributions of temperature and smoke particles with and without a smoke control system are compared. It is shown that the extraction system has a good smoke removal rate extracting smoke from the subway station with exhaust fans.

1. Introduction

A fire set by arson at Daegu Jungangno subway station was spread over all the 6 trains and killed 192 in February 2003. Investigations showed that the ventilation system supplying fresh air into the station failed to be switched to an emergency extraction system to remove smoke from the station.

Subway stations have several large openings that supply air enough for both combustion and smoke extraction. This makes the extraction system more efficient in smoke control compared with the ventilation system[1]. The extraction system removes smoke with exhaust fans whereas the ventilation system has blowers for air supply and exhaust fans for smoke removal.

Carrying out a full-scale experiment on the fire in a subway station has difficulties due to its large structure. On the other hand, development of computational fluid dynamics increases numerical simulations of fires in subway stations, tunnels, and underground structures. The NIST Fire Dynamics Simulator (FDS)[2] was applied to a fire in a small compartment of 4 m x 1 m x 1.5 m with openings[1]. Rie and Lew[3] carried out a numerical study on a 20 MW fire on a train vehicle in a full-scale subway station of 180 m x 30 m x 6 m with FDS.

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The objective of this study is to investigate smoke control performance of the extraction system in a subway station by using FDS. Through preliminary investigations, a small 200 kW polyurethane fire was chosen to investigate smoke movement in the part of a subway station.

2. Methodology

For detail information on fire and smoke movement, the part of a subway station around a stairway from the platform to the corridor was taken as the computational domain. As shown in Fig. 1, the computational domain includes the part of platform of 10 m x 3 m floor, 2.6 m high, and the corridor of 4 m x 3 m x 2.6 m. The width and slope of the stairway were taken to be 1.8 m (y= 1.2~3 m) and 45^o for convenience. Two outlets were located at the positions marked ‘o’ in Fig. 1, and its size is 0.6 m x 0.6 m. The locations of the openings and outlets were listed in Table 1.

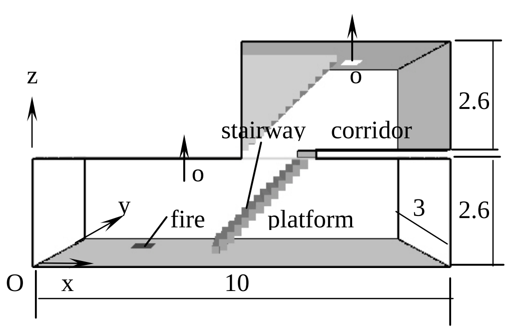

Figure 1. Computational domain (dimensions in m).

Table 1. Locations of outlets and openings.

centers of outlets	(3.25,2.1,2.6 m) (8.25,2.1,5.4 m)
openings	plane of x=0 plane of x=10m, z=0~2.6m plane of y=0, z=0~2.6 m

The fire scenario was set that polyurethane is combusting at a constant heat release rate, 200 kW. The size of the fire bed is 0.6 m x 0.6 m and its center locates at (2.1, 2.1, 0.0 m). The polyurethane was chosen since its combustion characteristics are available in the FDS database. The exhaust fan starts operation at 10 s (t= 10 s) from the onset of the fire. Without smoke control, the particles inserted into the flow field through the fire bed move out from the computational domain at t= 2.7 s, and the number of the particles in the domain increases with time (see Fig. 6). From this result, the exhaust fan starts in operation at t= 10 s to see the effects of smoke control. Since the number of particles remains almost the same for t> 20 s when smoke is controlled by the exhaust fan (see Fig. 6), computations were stopped at t= 50 s. The flow rate through each outlet was set to be 0.9 m^3/s (3240 m^3/h). The temperature of ambient air and walls was assumed to be 20^oC.

The unsteady three-dimensional turbulent flow with heat transfer including thermal radiation was simulated numerically by NIST FDS version 3.1[2]. None of the default values in FDS was modified. The grid system, 100 x 30 x 54, was used so that the size of each grid cell in the x-, y- and z-directions is uniformly 0.1 m.

3. Results and Discussion

Fig. 2 shows variation of temperature distribution with time at y= 2.1 m, that is, the midplane of the stairway, without the smoke control system. For convenience black region represents the temperature of 60^oC or above. The hot air moves along the ceiling and is accumulated in the space of the corridor.

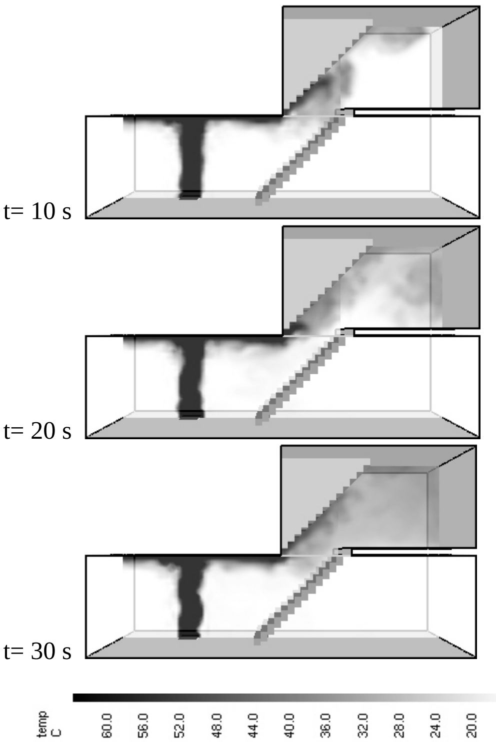

Figure 2. Temperature distribution on the plane of y= 2.1 m (without smoke control)

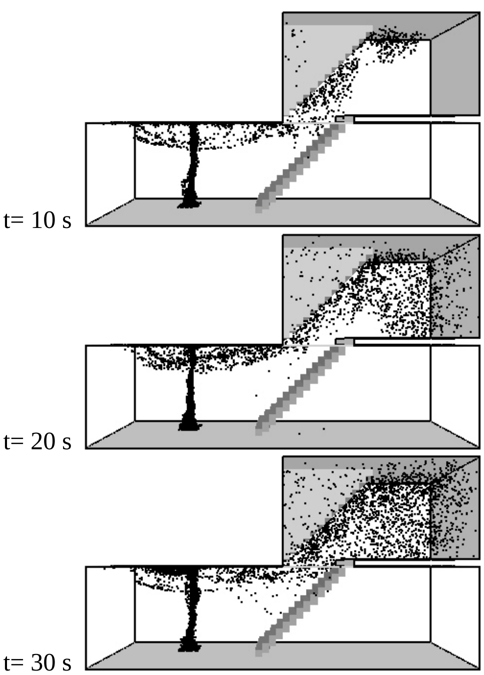

Figure 3. Particle distribution (without smoke control)

A similar development of particles is shown in Fig. 3. The number of particles increases with time. Since the particles do not have volume, mass, or any physical properties, traces of particles show smoke movement more realistically than temperature distributions.

Fig. 4 compares temperature distributions between with and without smoke control. As shown in Fig. 1, there are two outlets on the ceiling, and each extracts the air-smoke mixture at 0.9 m^3/s

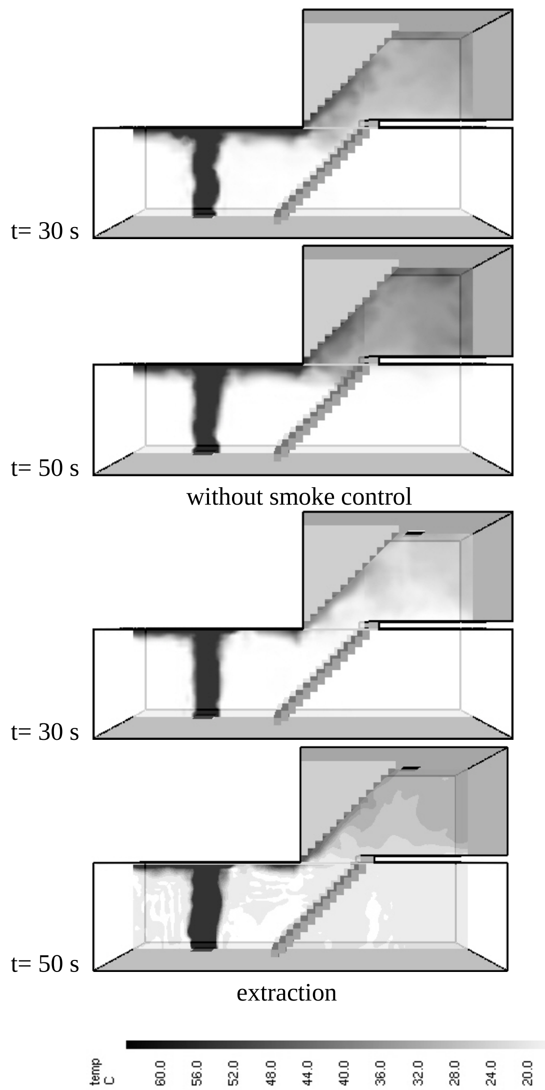

Figure 4. Comparison of temperature distribution (y= 2.1 m).

($3240 m^3/h$). Although temperature increases with time, when the extraction system is in operation from t= 10 s, temperature in the second floor is much lower than that without smoke control.

The effects of smoke removal can be shown more clearly by particle distributions than by the temperature distributions. Fig. 5 compares the particle distributions with and without smoke control. Without smoke control, the number of particles at t= 50 s is much more than t= 30 s. With smoke control, however, the number of particles is nearly the same due to extracting smoke particles by the exhaust fan.

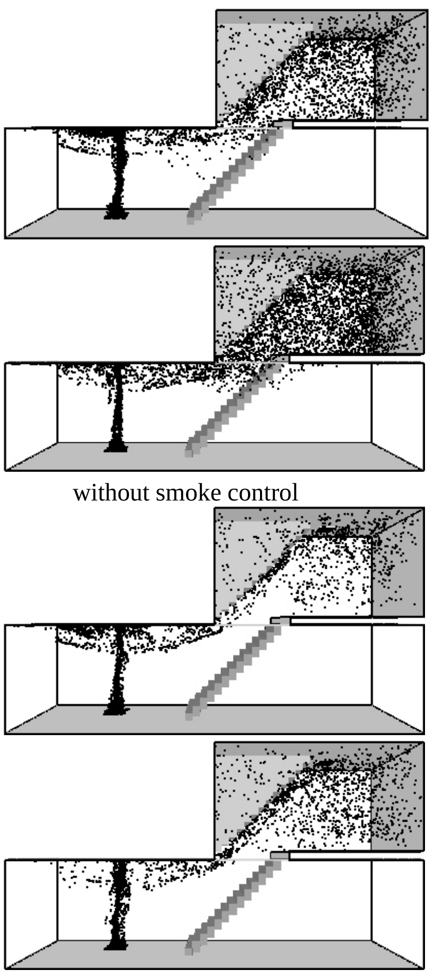

Figure 5. Comparison of particle distribution.

The variation of the number of particles remained in the computational domain with smoke control is compared with that without smoke control in Fig. 6. When the smoke control system is not in operation, the particles start to escape through the openings at t~2.7 s, and the number of particles suddenly decreases, then increases almost linearly with time for t>6 s. When the smoke control system is in operation starting at t= 10 s, about 4000 particles remains for t>20 s. The number of particles at t= 50 s was 6893 without smoke control, and 4205 with smoke control. These results clearly show that the extraction smoke control system has good smoke removal performance.

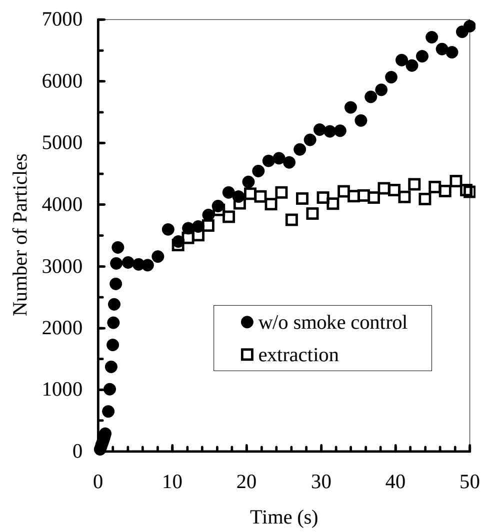

Figure 6. Variation of the number of particles with time.

4. Conclusions

A 200 kW polyurethane fire in a part of a subway station was simulated by using the NIST Fire Dynamics Simulator to investigate smoke removal rate. Comparisons were made between with and without the extraction smoke control system. The extraction system was set to operate in 10 s from the onset of the fire at a flow rate of 0.9 m^3/s each outlet. Distributions of temperature and particles, change of the number of particles showed that the extraction system has god smoke removal performance.

References

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