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Study on Disaster Prevention in Case of Fire at Subway Platform with Platform Screen Door

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Abstract : A study on fire phenomena in a subway transit mass station has been carried out as a part of disaster prevention plan at the subway station. The ventilation facilities installed in both the platform and the trackway are designed to convert into a smoke exhaust system in emergency situation, creating an environment necessary for evacuation. 3 dimensional Numerical Simulations based on the CFD are carried out using a simulation tool, Fire Dynamic Simulator. Total of six different cases are made and performances are compared each other to find optimal vents operation to ensure safer environment for evacuation at the platform area considering the installation of platform screen door.

Key words: subway fire, smoke extraction, fire dynamic simulation, platform screen door

1. Introduction

In 1995, about 300 people were killed and at least 250 injured when a crowded subway train caught fire in Baku, capital of Azerbaijan. In 2003, about 200 people have died in flames and smoke after a man apparently set fire to flammable liquid inside the subway train in Daegu, South Korea. In January of 2005, a fire at the subway system in New York City left two metro lines unable to return to full service for three to five years. From the previous experience, it has been realized that serious consideration should be made on the possibility of fire by arson or terrorism as well as accidental fire. [1-4]

In the present study, assessment of safety plan against fire at the subway platform is carried out. The existence of platform screen door (PSD) will be considered as a major factor that can influence the smoke and heat propagation behavior in case of fire. Furthermore, the heat and smoke propagation behavior induced by the possible breakdown of the platform screen door (PSD) due to the hot air stream will be also investigated.

Finally, optimal operation of vents to ensure the creation of the tenable environment for evacuation will be sought focusing on the smoke and heat removal efficiency.

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2. Description of Platform

Since Daegu subway fire disaster, several studies have been carried out to enhance the underground space safety. Especially, it was proved that appropriate operation of the tunnel vents can improve the condition for the passengers to evacuate during the fire emergency by effectively removing the heat and smoke to the outside of the subway platform. However, until now, studies have been done only for the case that the platform screen door (PSD) is not installed in the platform area. In the present study, existence of the PSD is considered as a major factor influencing the smoke and heat propagation behavior in case of fire. Furthermore, the breakdown of the PSD which is made of tempered glass, hence, allowing smoke and heat propagating through the door is also considered.

The target model is the platform No 5 on the extended Incheon metro line to Song-do which is currently under the detailed design stage.

Fig. 1 shows the structural view of the platform area with vents which have total capacity of 10000 CMH and the upper exhaust vents of the track exhaust system (TES). Fig. 2 shows the plane view of the two side platforms.

3. Methodology of Fire Safety Assessment

3.1 Numerical Analysis

For the numerical simulation a CFD tool, FDS (Fire Dynamics Simulator) ver.3 developed in NIST (National Institute of Standards and Technology) was utilized in order to simulate the heat and smoke propagation phenomena in case of fire at the subway platform.

The fire scenario is that a train which already caught fire on a carriage in the middle of the train enters and stops at the platform. If there is a PSD installed, PSD on the same side of the train is opened and PSD on the other side is still closed to prevent propagation of smoke and heat. Thereafter, the carriage burns up completely. The location of the fire point was 2.6 m high from the track surface.

The PSD which is comprised of door and side wall is made of tempered glass. Hence, PSD on either side of the platform can break down if the air stream temperature goes up beyond the critical point. In this study this possibility was considered when PSD is installed.

Observation is made for 240 seconds as the evacuation time needed for the escaper was calculated to be 240 seconds using SIMULEX, an evacuation simulator.

A total of 1,105,92 (64 × 720 × 24) control volumes were generated for the numerical simulation.

The fire intensity is assumed to be 20 MW which was applied to Los Angeles (21.4MW) and Boston (20 MW) transitway projects following American NFPA standards[9]. For fire source, methane is chosen for the simplicity of simulation of combustion process and reflecting that the interiors of the train have recently changed from the flammable to inflammable material.

Table 1 shows the modeling scenarios made by combination of the platform screen door option and vents operation. The initial temperature is assumed to be 30°C.

3.2 Validation of Grid Size

The quality and iteration time of the fire simulation depends largely on the grid size. Adopted LES turbulence model requires that grid size should be small enough to emulate SGS (Subgrid-scale stress). For the characteristic length scale, McCaffery suggested to use characteristic fire diameter calculated by equation (1).

$$D^* = \left[\frac{Q^*}{\rho_\infty \cdot Cp \cdot T_\infty \cdot \sqrt{g}}\right]^{\frac{2}{5}} \quad (1)$$

$$\delta = 0.1D^* \quad (2)$$

$$\delta > \delta_{x,y,z} \quad (3)$$

From the equation (1) and (2), maximum grid size, δ

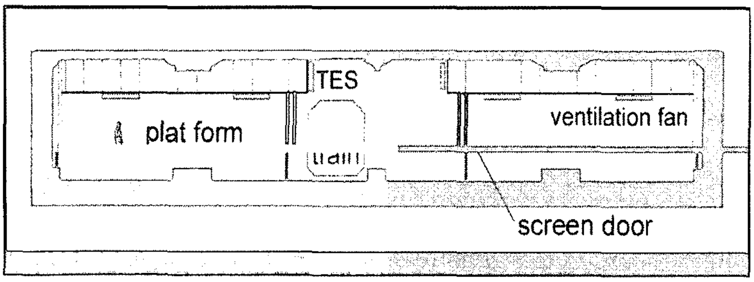

Fig. 1. Smoke extraction position in platform area

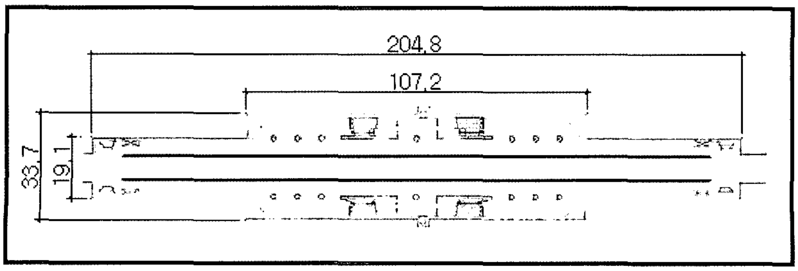

Fig. 2. Plane view of side platforms in subway station

Table 1. Modeling scenarios by combination of platform screen door option and vents operation

Case	PSD	Vent operation (Exhaust)	PSD breakdown condition
(1)	Yes	None	> 250°C
(2)	No	None	-
(3)	Yes	None	Never
(4)	Yes	Platform: 10000 CMH, TES(up): 100%	> 250°C
(5)	No	Platform: 10000 CMH, TES(up): 100%	-
(6)	Yes	Platform: 10000 CMH, TES(up): 100%	Never

is calculated as 0.79 m with the 20 MW fire Intensity. Applying grid numbers of 64 × 720 × 24 to the simulation target, subway platform which has the dimension of 31.5 m × 202.6 m × 6.1 m, the grid size is calculated to be δx=0.49 m, δy=0.28 m, δz=0.25 m. This value satisfies the grid size condition judged by equation (3), hence the validity of the grid size was confirmed.

3.3 Tenability Criteria for Evacuation

To assess the tenability on a specific case or scenario, definition of tenability criteria must be preceded. For the heat and smoke, standards defined in the NFPA 130 (1997) was adopted.

To maintain the evacuation route tenable in terms of heat, air stream temperature should be maintained below 60°C. For the smoke, the soot density should be kept below 65 mg/m^3 to ensure the visibility. Finally, a fractional incapacitating dose (F_{IN}) for exposures to CO, HCN, CO_2 and reduced O_2 is maintained below 1.0 for tenability.

3.4 Views of Smoke Propagation

4. Results

4.1 Mean Soot Density and Temperature at Platform

Mean soot density, Sm and temperature, Tm at the height of 1.5 m from the platform floor are calculated from equation (5) and (6).

$$Sm = \frac{\sum(Si \cdot Ai)}{\sum Ai} \quad (5)$$

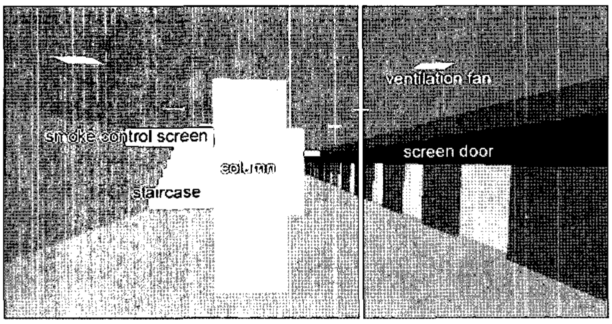

Fig. 3. View of stair and PSD

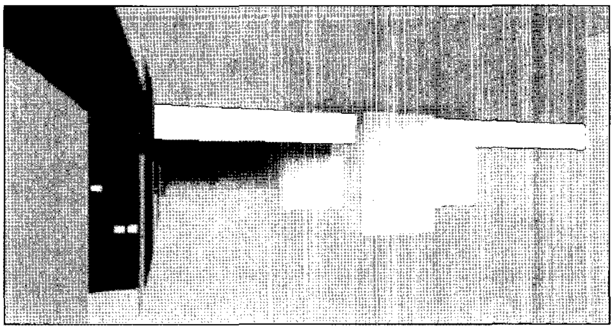

Fig. 4. View of smoke curtain

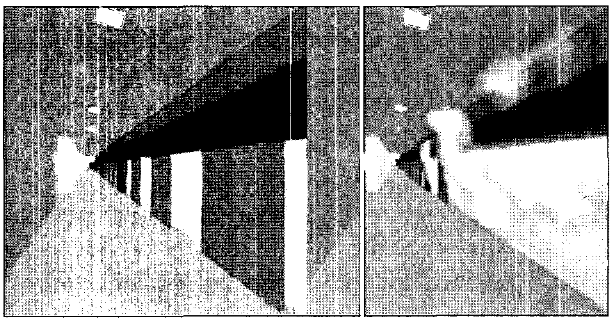

Fig. 5. Smoke propagation before and after the breakdown of PSD

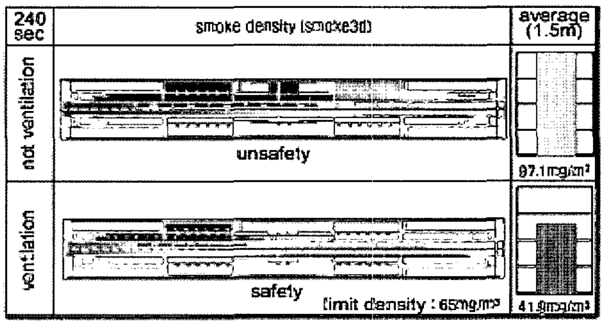

Fig. 6. Smoke density in the platform (240sec)

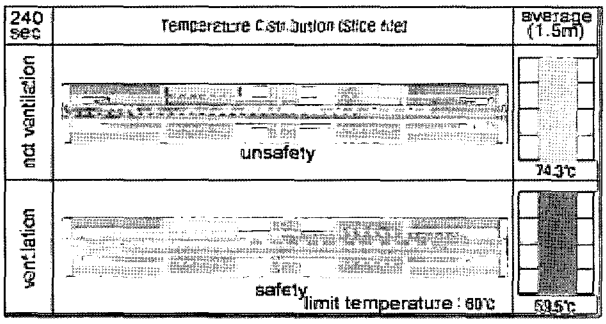

Fig. 7. Temperature distribution in the platform (240sec)

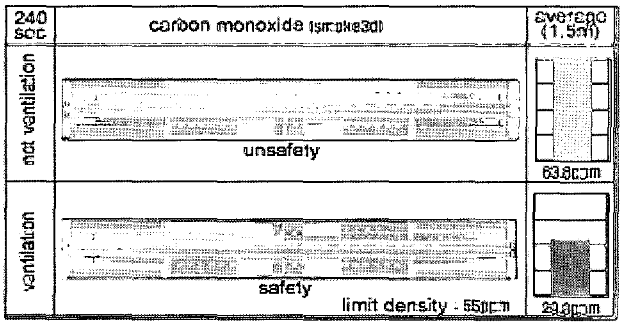

Fig. 8. CO distribution in the platform (240sec)

$$Tm = \frac{\sum(Ti \cdot Ai)}{\sum Ai} \tag{6}$$

4.1.1 Mean soot density at platform

Fig. 9 shows mean soot density at the platform while no vents operate during fire. PSD is installed in Case 1 and 3, but not in Case 2.

Case 1 and 3 are compared to investigate the effect of the possible breakdown of the PSD. In case 1, PSD breaks down at 250°C and, in case 3, it never break down. The mean soot density increases in the same rate for Case 1 and Case 3 until 60 seconds and start to separate afterwards. The difference is about 8% in 30 seconds later and reaches 48.4% difference in 240 seconds.

It is shown in Fig. 9 that Case 2 where PSD is not installed is 24 to maximum 42% lower in terms of soot concentration than in Case 1. This is because that in Case 1, the heat and smoke propagate only towards the side platform where the train on fire is parked but not to the opposite side platform because the closed PSD block its propagation.

In Fig. 10, mean soot densities of case 4, 5 and 6 where hot smoke is exhausted by the vents are compared. Comparison of Case 4 with Case 6 in Fig. 10 shows the effect of PSD breakdown. Until 60 seconds two graphs coincides but starts to separate afterwards. The increase rate of difference is about 7% in 30 seconds later and reaches 45% difference in 240 seconds. Comparison of Case 4 with Case 5 in Fig. 10 shows the effect of installation of PSD while vents are operating. Mean soot density at the platform reduced by 5 to 32%.

Comparison of Case 1, 2 and 3 with Case 4, 5 and 6 shows that the smoke vent contributes to lower the soot density about 50% of peak value, hence ensures safer environment for evacuation.

4.1.2 Mean temperature at platform

Fig. 11 shows mean temperature at the platform while no vents operate during fire. PSD is installed in Case 1 and 3 but not in Case 2.

Case 1 and 3 are compared to investigate the effect of the possible breakdown of the PSD which is made of tempered glass. In case 1, PSD breaks down at 250°C and, in case 3, PSD never breaks down. The mean soot

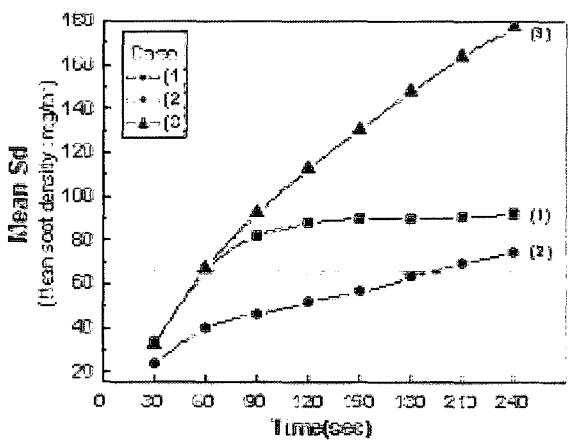

Fig. 9. Mean soot density of platform area

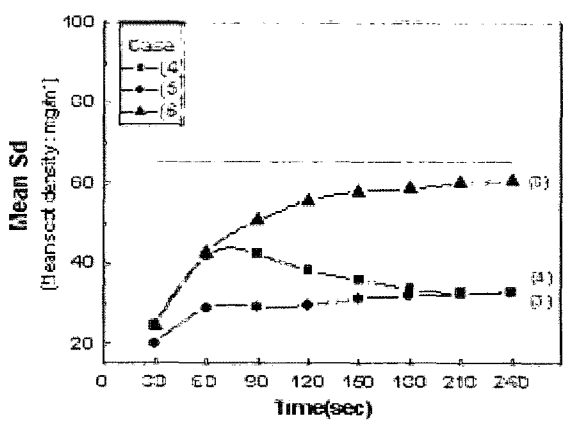

Fig. 10. Mean soot density of platform area

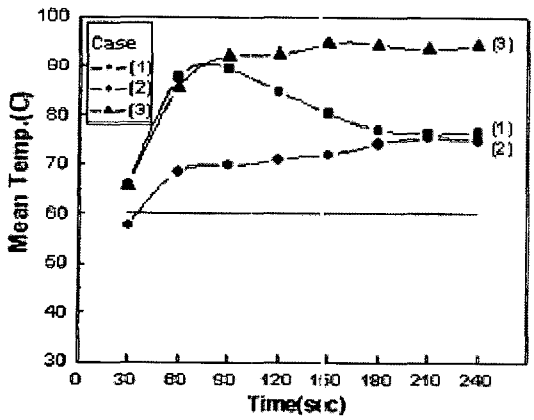

Fig. 11. Mean temperature of platform area

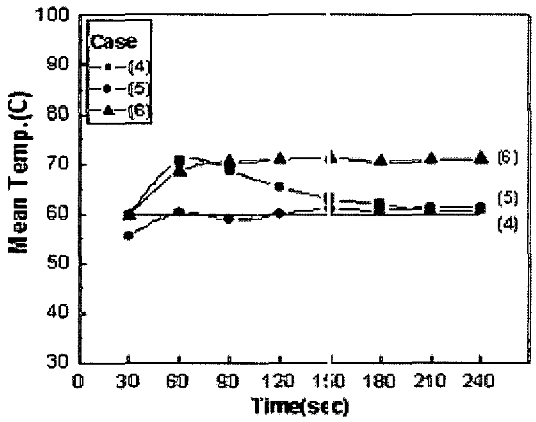

Fig. 12. Mean temperature of platform area

density increases in the same rate for Case 1 and Case 3 until 60 seconds and start to separate afterwards. The increase rate of difference is about 3% in 30 seconds later and reaches 19% difference in 240 seconds.

The effect of the installation of PSD can be seen by comparing Case 1 with Case 2. Until 120 seconds, maximum of 120% difference was observed but two curves start to meet afterwards.

In Fig. 12, mean platform temperature of case 4, 5 and 6 where hot smoke is exhausted by vents are compared. Comparison of Case 4 with Case 6 shows the effect of PSD breakdown. Until 70 seconds, two graphs coincide but starts to separate afterwards. The increase rate of difference is about 7% in 30 seconds later and reaches 15% difference in 240 seconds. Platform temperature in Case 4 and 5 shows substantial difference as in Case 1 and 2 until 120 seconds but the difference starts to diminish afterwards.

Comparison of Case 1, 2 and 3 with Case 4, 5 and 6 shows that the vent operation contribute to lower the temperature about 21% of peak value, hence ensures safer environment for evacuation.

4.2 Share Rate of Platform Area in Untenable Condition for Evacuation

The share rate of platform area where the soot density is over 65 mg/m^3 which corresponds to the criteria of the untenable condition for the evacuation of the passengers can be calculated using equation (7). Values from equation (7) is used to estimate the share rate (%) change of untenable area due to smoke along with time, such as 150sec and 300sec from the fire occurrence. The share rate of area was estimated at 1.5m high from the platform floor. Furthermore, share rate of platform area where the temperature is over 60°C is calculated using equation (8).

$$AC\% = \frac{A65C}{A} \tag{7}$$

$$AT\% = \frac{A60T}{A} \tag{8}$$

From equation (9), a fractional incapacitating dose (F_{IN}) for exposures to CO, HCN, CO_2 and reduced O_2 is calculated.

$$FIN = \sum_{i=1}^{n} \{(F_{ICOi} + F_{ICNi})V_{CO2i} + F_{IO2i}\}\Delta t_i \tag{9}$$

A value of 1 or more indicates incapacitation.

4.2.1 Share rate of area in untenable condition by smoke

Fig. 13 show the share rate of area where soot density is over 65 mg/m^3 in 120 and 240 seconds from fire occurrence.

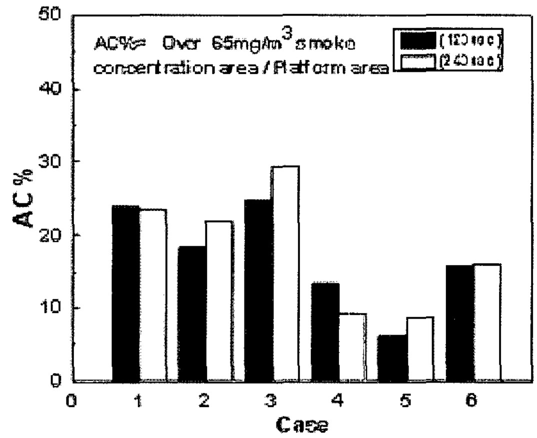

Fig. 13. Share rate of area where soot density is stream over 65mg/m^3

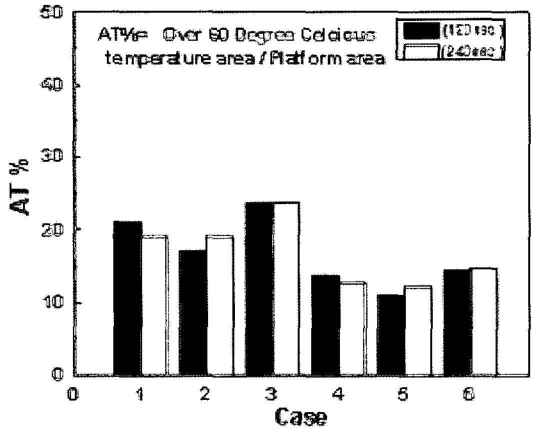

Fig. 14. Share rate of area where air temperature is 60 mg/m^3

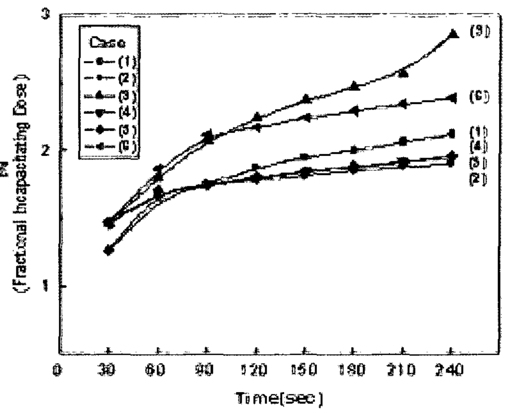

Fig. 15. Fractional incapacitating dose (FIN) of different cases

Results from Case 1 and 3 show that the share rate of area in untenable condition by soot is higher when PSD does not break down. The minimum share rate is observed as 21.8% in Case 2 where PSD is not installed.

Among Case 4, 5 and 6 where smoke is exhausted through vents, minimum share rate is observed as 8.7% in Case 5 where PSD is not installed. Overall, if there is vent operation for smoke exhaust, share rate of area in untenable condition by smoke reduces 50% than the case when there is no vent operation.

It is also known that share rate of area is higher when PSD is installed than none. Hence, it is recommended to enhance smoke exhaust system using vents when PSD is installed. As there is a possibility that installation of PSD in the subway platform is mandated by standards or regulations, enhancement of the smoke exhaust system should be carried out.

4.2.2 Share rate of area in untenable condition by heat

Fig. 14 show the share rate of area where air stream temperature at the platform area is over 60°C in 120 and 240 seconds from fire occurrence.

Results from Case 1 and 3 show that the share rate of area in untenable condition by temperature is higher when there is no PSD breakdown. The minimum share rate is observed as 19.1% in Case 2 where PSD is not installed.

Among Case 4, 5 and 6 where smoke is exhausted through vents, minimum share rate is observed as 8.7% in Case 5 where PSD is not installed. Overall, if there is vent operation for smoke exhaust, share rate of area in untenable condition by heat reduces about 47% than cases where there is no vent operation.

4.2.3 Share rate of area in incapacitation condition

Fig. 15 shows the fractional incapacitating dose (FIN) of different cases.

Comparison of Case 1, 2 and 3 with Case 4, 5 and 6 shows that fractional incapacitating dose (FIN) is higher when smoke exhaust through vents is not running.

The lowest incapacitation condition is observed in case that there is no PSD and the highest incapacitation condition is observed when PSD is installed and the door is under no breakdown condition.

5. Conclusions

From the results of the numerical study to investigate the effect of the installation of PSD and possibility of door breakdown in case of fire at the subway platform, the following conclusions were drawn

1) From the analysis on cases where PSD is installed and the PSD breakdown is a possible scenario,

① if there is no smoke vent operation, the mean soot density is higher 8 to 48.4% when PSD breaks down than the case where PSD never breaks down. In terms of mean temperature, the range is 3 to 19%.

② if there is smoke exhaust through vent, the mean soot density is higher 7 to 45% when PSD breaks down than the case where PSD never breaks down. In terms of mean temperature, the range is 3 to 15%.

2) If there is vent operation for smoke exhaust, it contributes to lower the soot concentration around 50% and temperature around 21% than cases where vents are not operated, hence ensures safer environment for evacuation.

3) It is observed that share rate of area in untenable condition due to heat and smoke is higher when PSD is installed than none. Hence, it is recommended to enhance smoke exhaust system through vents when

PSD is installed. As there is a possibility that installation of PSD in the subway platform is mandated by standards or regulations in Korea, enhancement of the smoke exhaust system should be carried out.

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