Performance-based Fire Safety Design for Smoke Management
System in the Subway Platform

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Abstract

The fire safety system at Daegu subway station had inherent problems from which many casualties came. The main problem areas include that fire safety system design wasn't consider fire scenario including fire size, fire growth rate, fuel type, and smoke production rate. The Subway cabin design also focused on convenience and low cost, rather than cabin safety, and fire performance. Under these circumstances a performance based fire safety design approach is essential in ensuring safety in subway stations. Performance-based design for subway station and platform would consider the problem of the interrelationship between safety level and cost, fire size of subway car, smoke production rate, and identifying smoke control zone along egress route. The study reviews fire size and smoke production rate from burning cabin as fuel to determine the scale of smoke management system in the egress route. This will assist in implementing a performance based safety design at subway stations including the platform.

1. Introduction

In Daegu subway fire on Feb. 18 2003, Many concealed fire safety problems of subway station in Korea were come to the front. Fire safety system design and installation for Dae-gu subway station was completely legal and adapted to Korean fire safety laws in those days. However, Fire safety system on Dae-gu subway station failed to protect evacuee when fire happened.

One of the reasons why fire safety system was useless derives from the limitation of prescriptive law in Korea. Most of fire safety designers only consider that the design adapt to the specifications of law, and Authorities having jurisdiction checked whether the design is out of it or not. They don't consider fire scenarios including fuel type, fire size, fire growth

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rate, and smoke production rate. In principle fire safety design requires the consideration of fire scenarios including fuel type, fire size, and fire growth rate. These items are essential for the respiratory damage to the victim, which generally comes first in case of fire, due to confine spaces as subway tunnel.

Therefore, performance-based design approach to ensure the safety on subway station, especially platform, from fire would be considered. In this paper, the problems of performance-based design application for smoke management system on subway platform were reviewed. the problems of smoke management system design for subway platform also were identified through performance-based analysis.

2. Problems of Performance-based Design Application for Smoke Management System on Subway platform

2.1 Problem of Fire Safety Level and Cost

Safety goal of smoke management system on subway platform is to prevent loss of life caused by smoke filling. Fire-generated smoke in subway station flows to the ground through vertical openings and shafts. Normally, Pathway of smoke movement and egress route are the same because main shaft in subway station is stairways. Evacuee should use stairways when they attempted to egress, so walking speed of evacuee is not fast. The disabled, old persons, and children need the time to survive until rescue unit arriving. Therefore, Identifying safety level of

smoke control design depends on the period to protect evacuee from smoke. Smoke exhaust rate is equal to smoke production rate in order to prevent smoke filling. However, we seriously think over financial problems if high capacity ventilation is demanded. In this case, smoke exhaust rate would be downsized considering the interrelationship between fire growth and egress time. This plan pulls down safety level but reduce the cost. The other alternative plan for solving that problem is to reduce total quantity of fuel as interior finished material of subway car. Consequently, most effective design plan using performance -based analysis should be developed. Identifying safety level of subway car materials also is related with smoke management system design.

2.2 Problems of Identifying Fire Size & Smoke Production Rate

Before Dae-gu subway fire, nobody predicts subway car fire occurred by arsonist on subway station in Korea. The smoke exhaust system in the platform against the subway car fire was demanded since that case happened. However, the design guideline to define the smoke exhaust rate for subway platform is not ready. Especially, fire size of subway car is inaccurate at present. Fire characteristics of Subway car including fire growth rate and maximum fire size are very important for Performance - based analysis about smoke management system.

The best way to know the fire size, smoke product rate is the measurement using large cone-calorimeter. However, a

subway car cost about \ 1,000,000,000 ~ \ 1,600,000,000 (U.S.D. $ 870,000 ~ $1,400,000). Fire test of subway car also conduct every time when interior materials and car size changed. For that reason, only one test is not easy practically now. Therefore, alternative plan is the prediction of full-scale test result by the result of small-scale measurement.

This study predicted the heat release rate of subway car from small-scale test result. Small cone calorimeter test for the heat release rate of interior materials presents peak value and average value. The Following table 1 presents the H.R.R. values of two type of subway car by cone calorimeter test for high and low grade interior materials:

Table 1. Total H.R.R. of subway car

		Peak H.R.R. (kW/m²)	Average H.R.R. (kW/m²)
Low Grade Materials	Subway Car A (L-A)	57,396.99	20,830.61
	Subway Car B (L-B)	74,746.26	24,932.28
High Grade Materials	Subway Car A (H-A)	28,705.69	13,516.89
	Subway Car A (H-B)	38,127.68	19,955.30

The ventilation-limited situation was considered in order to identify maximum H.R.R. The post-flashover analysis was performed for Subway Car-A using CFAST model. As a result, Maximum H.R.R. reached at 37.94 MW where fire size was 50 MW steady state. According to the result of EUREKA project in Europe, Maximum H.R.R. of subway car measured 35 MW.[2]

Consequently, It is predicted that fire size of car doesn't reach total H.R.R of those car estimated by peak value, except the result of H-A.

It is unclear that total H.R.R estimated by average value is approximately equal to real one.

Identifying fire size of subway car is so difficult and here, fire propagation between cars is not considered in this case. For designing smoke exhaust rate, it is essential to decide a fire size of subway car and develop the correlations between fire size and smoke production rate.

2.3 Problem of Smoke control zone design

Smoke from fire in underground structure flows through the vertical opening and shaft and release to the ground. Main shaft of subway station in underground is stairways. It means that pathway of smoke movement and egress route are same. That was the reason why many people were killed in subway station fire.

Local fire code requires smoke control zone in subway station by floor area now. However, this is not a effective to protect egress route because smoke management system must protect the stairway and egress route that is apart from fire. So Smoke control zone in subway station should be planed and designed along with egress route.

3. An Application of Performance

-based Design for Smoke management system

The case study for subway platform was conducted in which the design of smoke exhaust system and draft curtain is applied. In this analysis, some assumptions from subway car fire size and smoke production rate is suggested. Field model FDS 3.1 was used for analysis.

3.1 Developing smoke management system design and identifying fire size

Smoke control zone set on the basis of one side of platform and is shared middle point of it. Smoke control zone divided into platform and railway using draft curtain.

20 MW steady fire is used because the standard station facility and equipment safety improvement plan from public hearing committee proposes maximum H.R.R. of subway car composed by A grade materials is 15 ~ 20 MW.

It was assumed that smoke production rate was $20m^3/s$ using the predictive equation of mass flow rate by Tomas and considering safety margin.

3.2 Evaluate the design of smoke management system

1) Geometry and Vents

Assuming that subway platform is enclosed within a 90m wide x 15m depth x 5m height rectangular volume. The dimension of subway car was 19m length x 3m wide x 2.25m height. The platform has two stairs as a opening and vents. Vents installed the smoke control zone on both sides. Smoke exhaust rate of each side was 20 m^3/s and total rate was $40m^3/s$.

For the FDS simulation, this volume was divided into 216,000 computational cells.
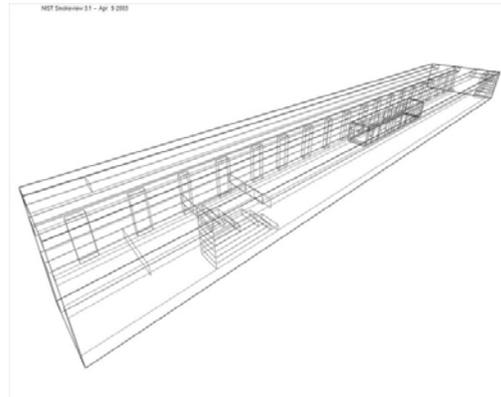
Figure 1. Wire frame of Structure
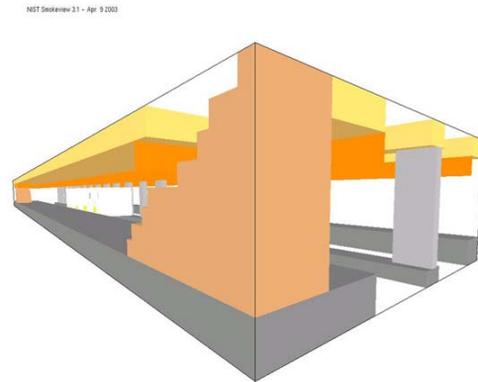
Figure 2.   Stairs, openings, and subway

2) Modeling and result

As a result, smoke layer interface descended to 2.5 m height from platform floor. Figure 3 shows smoke layer interface at 220 sec and 580 sec. Figure 4 shows smoke layer temperature nearby stairway

does not exceed 70℃ and interface temperature is around 25~40℃. Smoke is flowing through opening on stairways.

(a) 220 sec into simulation

(b) 580 sec into simulation
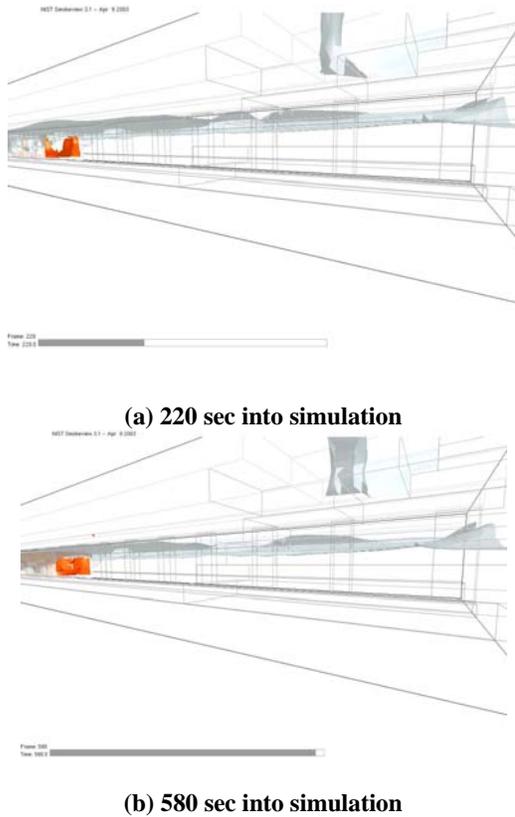
Figure 3. Smoke Interface

Figure 4. Thermal conditions at 400sec and 560sec into simulation

3.4. Analysis

The result of modeling shows that the smoke exhaust rate assumed was not enough to protect the egress route because of smoke releasing through opening on stairways.

If smoke exhaust rate increasing more higher, it is needed to adjust the safety level to delay smoke filling rate and have to consider to reduce the limitation value of total H.R.R. of Subway car.

4. Conclusion

The conclusion of this study is as follows;

1. A Smoke exhaust rate on the platform is to be decided by the safety level of design purpose. If huge cost is demanded by the design of high capacity ventilation system, quantity of fuels should be downsized or the safety level down.

2. Identifying fire size of subway car was so difficult. In addition, fire propagation between cars was not considered. If we want to identify smoke exhaust rate, study about fire size of subway car would be conducted and the correlations between fire size and smoke production rate should be developed.

3. Local fire code requires smoke control zone in subway station by floor area now. However, this is not an effective to protect egress route because smoke management

system should protect stairway and egress route that is normally apart from fire. So Smoke control zone in subway station should be planed and designed along with egress route.

4. The result of modeling shows that the smoke exhaust rate assumed was not enough to protect the egress route because of smoke releasing through opening on stairways. Smoke exhaust rate per a zone is raised when new trial design will be estimated. If smoke exhaust rate increasing more higher, it is needed to adjust the safety level, to delaying smoke filling rate and have to consider to reduce the limitation value of total H.R.R. of Subway car.

In conclusion, Smoke management system in subway platform should be designed considering fire size of subway car and smoke production rate. Identifying scale of smoke control zone by floor area should be changed. Smoke management system design and identifying grade of interior materials of subway car should consider each other.

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