Fire Safety Evaluation of Urban Buildings

Dong-Seung Baek, Kyung-Bum Lim

***Abstract:** As buildings have been getting taller and incorporating more intelligent designs due to industry development and population growth, property damage and the numbers of casualties resulting from fires are increasing, which requires safety evaluations that involve engineering analysis methods. This study analyzes the use of safety measures against fire hazards, by conducting fire simulations to calculate the visibility range and radiant/convective heat in CO/CO2/smoke, and by performing evacuation simulations to analyze the ASET(Available Safety Egress Time)/RSET(Required Safety Egress Time). From the results of the fire/evacuation simulations, it is possible to estimate the impacts that fire hazards (e.g. toxic gases and temperatures) can have on the occupants' safety, to examine the feasibility of the evacuation/fireproof equipment in buildings for unspecified individuals, and to establish an optimized evacuation plan to minimize damage or loss of life. It is expected that fire simulations will enable the following activities: risk impact evaluation analyses, laboratory safety inspections, establishment of safety assessments for construction works, and future continuous research studies linked to super high-rise buildings.*

***Keywords :** Fire safety, Safety evaluation, Evacuation safety assessment, Fire simulation, FDS.*

I. INTRODUCTION

As the recent rapid industrial/technological developments have led to an increase in the number of high-rises and intelligent buildings, property damage and loss of life due to fires are problems that are ceaselessly growing [1,2]. The damage is expected to be minimized if measures are established against fires in building structures, taking into consideration engineering analysis methods which calculate the movements of smoke and diverse toxic gases, and that evaluate the evacuee risks as well [3,4]. To find out what causes a fire, safety evaluations through tests in an actual-sized sites are the best method. However, those tests that involve actual-sized materials require large budgets and time periods, and also result in extremely limited information. For that reason, in the actual practice of building design in developed countries, the traits of fire spreading and evacuations observed in simulations based on simplified fire tests are widely accepted [5-7]. Combining an analysis of various fire situations from the viewpoint of the liberal arts/social sciences with engineering risk prediction methods, this study examines the utility of ensuring safety against diverse fire hazards through a convergent safety/risk analysis.

II. EXPERIMENTAL

A. Fire-simulative evaluation method

The factors that can increase the occupants' risks during a fire are generally categorized into: heat, visibility range, and toxic gases. As shown in Table-1, this research has adopted the domestic criteria for the protection of the occupants' lives in evacuations due to a building fire.

The analyzed risks are compared with the information suggested in the life safety criteria. When a resulting number exceeds the standard value, the relevant spot is determined as a dangerous zone. Then, the time difference between the starting point of the simulation and the point of the danger-zone determination is considered as the ASET (Available Safe Egress Time) [8,9].

Table-1: Life safety standard

Division	Performance Criterion
Breath Threshold	1.8m from the floor
Influence by Heat	60℃ or less
Visible Distance Influence	Other Facilities: 5m, Sales Facility: 10m
Toxic Effect	CO : 1,400ppm HCN : 80ppm O2 : 15% or more CO2 : 5% or less

B. Evacuation-simulative evaluation method

To predict the occupants' movements during an evacuation is a key aspect of the performance-centered building fire-safety analysis method. Evacuations during a fire are delayed by various causes, which lead to an increase of the total RSET (Required Safe Egress Time) [10].

This fire-safety evaluation used two programs (Pathfinder, SIMULEX) in a simulation to improve the safety of buildings against fire. In using Pathfinder, the SFPE mode and steering mode were applied. The simulation was conducted for 3 cases in total, and the result with the most conservative total RSET was then adopted as the analysis criteria [11-13].

C. Fire-safety evaluation method

The ultimate goal of a fireproof design is to enable all the occupants in a building to move into the shelters prepared by the design before damage occurs, due to factors such as smoke, in the case of a fire in the building.

The assessment of a fireproof design is conducted by comparing the time taken until the occupants in a building will become endangered after the fire breaks out and the time taken until the occupants complete their evacuation.

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In this situation, the minimum time required to complete the occupants' evacuation is called the REST; and time taken until they're in danger due to the fire is named the ASET [14-16].

When the RSET figure is equal to or less than the ASET, the goal of the fireproof design is considered to have been achieved. Otherwise, it is determined that the evacuative safety performance has not been secured.

III. ANALYSIS OF A FIRE SIMULATION

A. Setting of the fire simulation

In the fire safety evaluation, a detailed scenario of the fire simulation was calibrated to assess the impacts of the fire in a facility that has a high occupant density at specific times and is also expected to accommodate many random people.

Fire simulation modeling and conditions are shown in Fig. 1 and Table-2. To calculate the worst possible conditions, the caloric value was set at a number reached when a refrigerator is on fire with a strong intensity. Because all the occupants would be able to perceive the fire by themselves, it was set that all of them would begin the evacuation when a sensor activated an alarm. In addition, considering the occupancy and usage of the facility, the doors of every room were set as not locked, and another condition was added that the firefighting equipment would not work. Based on the above fire scenario, modelling and configuration, the fire simulations were conducted.

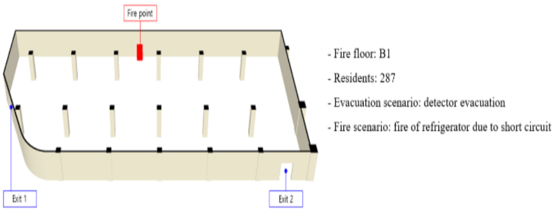


Fig. 1.Fire simulation modeling

Table-2: Fire simulation conditions

Division	Contents	
Interpretation grid number	542,520	
	Single mesh(274×110×18)	
Grid resolution	δx : 20cm	
	D*/δx	
Initial temperature	20 ℃	
Ignition material	Polyurethane(CH1.8O0.3N0.05)	
Fire scenario	Refrigerator fire caused by short circuit	
Maximum calorific value	3,100kW	
CO emission rate	0.010 kg/kg	
Smoke generation rate	0.131 kg/kg	
Disaster prevention equipment	Detector	Smoke detector (Estimation of evacuation delay time)
	Sprinkler	Not working(Consider worst case conditions)
	Ventilation equipment	Not working(Consider worst case conditions)

B. Results of the fire simulation

Fig. 2 and Fig. 3 show the fire simulation results. The results of the simulation assessed the risk factors by time using a fire interpretation program, taking the distribution of the visibility range/temperature by time during the fire as indicators.

The FDS evaluated of the visibility ranges by applying an extinction coefficient, meaning the intensity ratio of the lights received at a light-emitting source and a light-receiving source, when a light moves from the light-emitting source to the light-receiving source at a certain distance. The calculation of the visibility range in the FDS was conducted by using the equations suggested in the SFPE Handbook of Fire Protection Engineering.

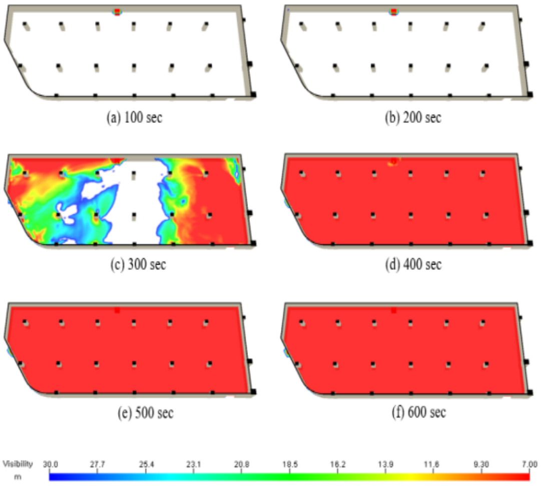


Fig. 2.Visible distance distribution over time

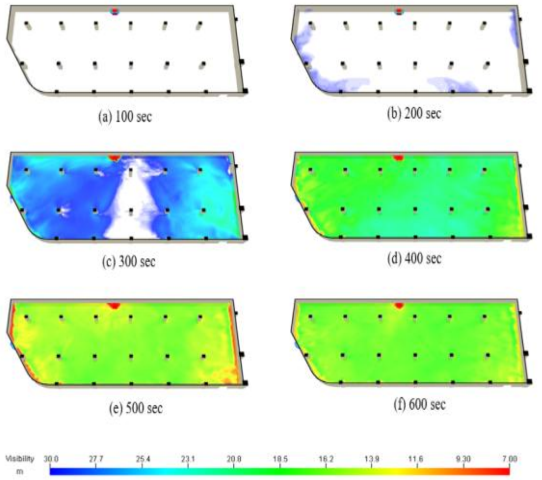
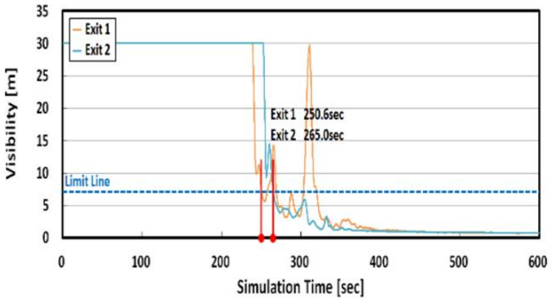
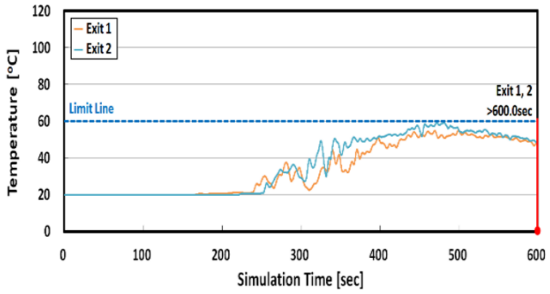


Fig. 3.Temperature distribution over time

Fig. 4 shows the safety assessment according to the duration of the fire. The results of the visibility range distribution in the time lapse of the fire didn't have an influence on the visibility range until a time of 200 seconds was reached. The effect was seen from 250.6 seconds at Emergency Exit 1, and from 265.0 seconds at Emergency Exit 2. The safety evaluation by temperature was conducted with a criterion of 60 ℃, by referring to the life safety standard. In the results, both of Emergency Exit 1 and 2 indicated a temperature lower than 60 ℃ as the fire rose.



(a) Visibility



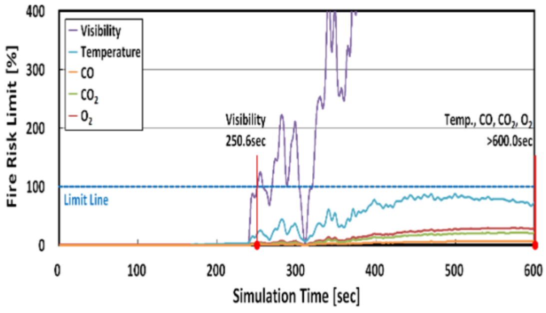
(b) Temperature

Fig. 4.Safety evaluation according to fire progress time

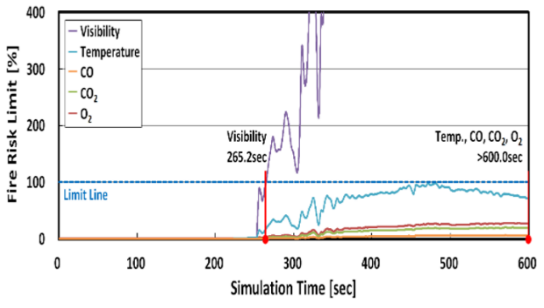
C. ASET analysis

The results of a fire simulation at the first basement level were analyzed to piece together the changes in the fire risks by time, and to calculate the ASET for each emergency exit. Fig. 5 shows the evacuation allowance time for each evacuation zone.

When the heat, visibility range and toxic gases (CO, CO2, and O2) were comprehensively analyzed, it was found that both Emergency Exits 1 and 2 were most strongly affected in terms of the visibility range.



(a) Exit 1



(b) Exit 2

Fig. 5.Evacuation time according to fire risk

IV. ANALYSIS OF THE EVACUATION SIMULATIONS

A. Setting for the evacuation simulation

Fig. 6 shows the evacuation simulation modeling conditions. To perform the fire evacuation simulations, certain conditions including the number of evacuating people were decided beforehand. Because the occupants were able to perceive the fire by themselves before evacuating the rooms due to their characteristics, an immediate evacuation was applied so as not to allow a delay time before the notification, action-taking and the evacuation start.

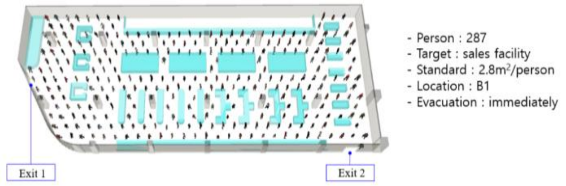


Fig. 6.Evacuation simulation modeling

B. Results of the evacuation simulation

The results of evacuation simulation analysis are shown in Fig. 7. As a result of interpreting a human evacuation after the fire evacuation simulation, the time until the completion of the evacuation was 95.4 seconds when applying Pathfinder SFPE, 76.1 seconds when applying Pathfinder steering, and 78.3 seconds when applying Simulex.

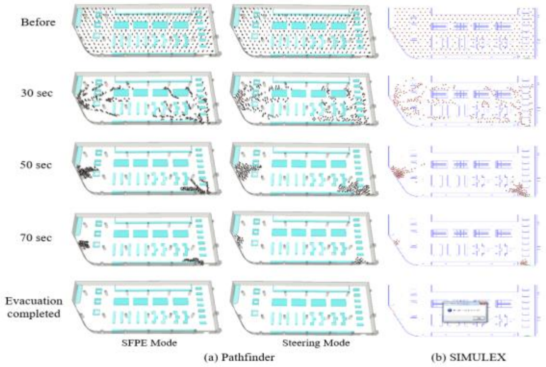


Fig. 7.Evacuation simulation result

C. Analysis of the RSET

Table-3 shows the results of evacuation time required for each exit. When analyzing the fire evacuation simulations and calculating the REST for each emergency exit by adding up the most conservative result and the detection time, the RSET didn't exceed the ASET. Therefore, it was evaluated that the occupants' evacuative safety in the fire was secured.

Table-3: Evacuation time by exit

Division	Exit 1	Exit 2
Pathfinder(SFPE Mode)	71.9 sec	69.6 sec
Pathfinder(Steering Mode)	52.6 sec	52.6 sec
SIMULEX	54.0 sec	54.8 sec
Simulation time	71.9 sec	69.6 sec
Detection time	23.5 sec	23.5 sec
Required Safe Egress Time(RSET)	95.4 sec	93.1 sec

V. CONCLUSION

In this study, a fire safety evaluation was conducted for a specific space through fire/evacuation simulations for ensuring safety in a fire. The comprehensive safety assessment, based on non-functional firefighting equipment, revealed that a more effective evacuative safety performance can be secured by involving ties with firefighting equipment

When introducing the concept of a performance-centered fireproof design with consideration of the domestic/overseas laws and standards, and when establishing a proper and reasonable fire safety plan with integrity to the building's usage suggested in the design, it must be able to secure the safety of the property and protect as many lives as possible.

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