Korean Review of Crisis & Emergency Management 10(1) Jan. 2014 215-224
Available online at www.cemtp.re.kr http://dx.doi.org/10.5392/CEM-TP.2011.

고층건물의 계단층에서 피난 및 제연에 관한 연구
A Study on the Evacuation and the Smoke Control in a Stair Shaft of a High Rise Building

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Abstract

Developing smoke control methods in high-rise buildings has been an object of much study in recent years in South Korea. When a fire occurs, the stair shaft becomes a vital means of evacuation. It also becomes an entry way for toxic gases. This paper considers whether it would be profitable to install a smoke control system in a stair shaft to reduce the spread of smoke. Using the software program SIMULEX, researchers investigated how long and with what degree of safety it took residents to evacuate a ten-story building. A CFD simulation was also performed to analyze how toxic gases were propagated and to see how long it took the gas concentration to return to a steady state. There were three cases studied. The first looked at a high-rise with just an ordinary staircase. The second case involved a high-rise where each floor was equipped with an exhaust fan. The last simulated a high-rise equipped with a fire protection curtain. Researchers also conducted experimental tests to compare with results from the simulation. The final evacuee, in the experiment, reached the roof exit in 254 seconds, compared to 180 seconds in the simulation. Researchers also wanted to know the time elapsed before 50 mg/m2smass flux of CO flowed through the roof exit. They found that in the ordinary staircase it took 38 seconds, and in the second case, with the exhaust fans, it took 61 seconds (the best result); the fire protection curtain yielded a result of 43 seconds. The exhaust fans were capable of reducing the CO mass flux by 33% of the ordinary staircase (9.8% lower than with the fire protection curtain).

Key words: Evacuation Characteristics, Smoke Movement, Building Fires.

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Submission & Publication Process
Received: Nov. 13, 2013 / Revised: Dec. 25, 2013 / Accepted: Dec. 31, 2013

국문초록

본 연구에서는 공동주택 화재 시 재실자 피난특성에 관한 연구를 위해 화재 실물실험을 수행하였고 동일대상에 대해 피난대피시뮬레이션을 수행하였다. 그리고 실물실험과 동일한 건물과 조건에서 화재 시뮬레이션을 수행하여 계단실에 방재설비 설치 유·무에 따른 독성가스의 전파 특성 및 최상층까지의 도달시간 등을 비교·검토하였다. 본 화재모의실험과 피난대피실험 결과 최종대피시간은 254초이며, 시뮬레이션 결과는 180초이다. 이러한 두 결과의 차이는 피난대피 시 대피자의 가시거리 확보와 독성가스에 의한 호흡 등에 어려움이 존재하기 때문이다. 또한 동일한 건물에서 화재시뮬레이션 결과, 옥상 출구에서 약 50 [mg/m2·s]의 CO 질량유속이 배출되는데 걸리는 시간은 case 1의 경우 약 38초가 소요되었으며, 배연 팬(case 2)과 제연커튼이 설치(case 3)되어 작동되는 경우 약 61초와 43초가 소요되었다. 또한 80초 이후에 일정한 CO의 질량유속은 층간 계단실에 배연 팬과 제연커튼이 없는 현재의 경우 약 78.2 [mg/m2·s]이며, 배연 팬과 제연커튼이 설치되어 작동되는 경우는 각각 약 52.3 [mg/m2·s]와 70.5 [mg/m2·s]이다. 따라서 층간에 배연 팬과 제연커튼이 설치되어 작동되는 경우가 배연 팬과 제연커튼이 없는 경우보다 각각 약 33%와 9.8%의 CO 질량유속을 줄일 수 있을 것으로 판단된다.
주제어: 피난 특성, 연기 이동, 건물 화재

Ⅰ. INTRODUCTION

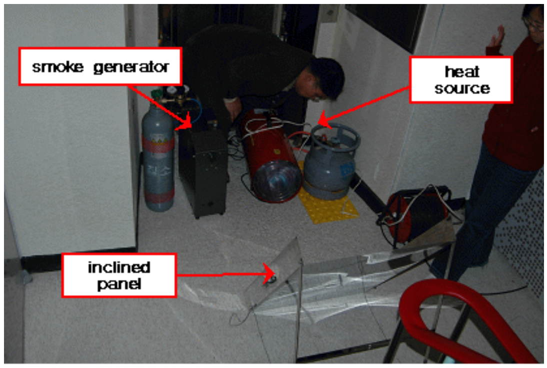
As Korea's population has increased, high-rises have become commonplace. Since 1970, government policy has encouraged apartment housing; today it accounts for more than half of all residential buildings[1]. Along with this increase, there has been an increase in the risk for fire[2]. If occupants are to be saved when fire breaks out in a high-rise, equipment that prevents smoke from obstructing evacuation paths must be in place. The Korean Department of Fire Safety has reported that when fires occur, many people(about 31%) asphyxiate from carbon monoxide(CO). Also the smoke blocks occupants' route to safety. The present study first investigates how much time is needed for people to flee an apartment fire. The study then includes a computer simulation of the same situation. Third, using computer fluid dynamics researchers studied the characteristics of the toxic gas movement; they looked at how long it took toxic gas to reach the high-rise's top story. Finally suggestions are made for reducing casualties.

II. METHOD FOR EVACUATION EXPERIMENT AND SIMULATION

1. An experiment for fire evacuation

These researchers conducted the experiment in a five-year-old, ten-story dormitory <Figure 1> at Kangwon National University, located in the Samcheok district of South Korea. The building, separated into three fire safety zones, houses 324 people; its height is 29.5 meters; its area is 5,132m2. The area of the stair shaft lies within the larger yellow outline, while its entrance is marked by the smaller yellow outline. The small red box, marking where the fire occurs, is on the second floor. The exits on the roof and ground floor are left open[3].

<Figure 1> The Building Used in Experiment



<Figure 2> The Experimental Apparatus on the 2nd Floor

2. Experimental method

A total of 103 individuals participated in the experiment 66 students, 12 firemen, and 25 assistants, all of whom were all trained in fire safety before the test. The experiment's apparatus included a smoke machine, an inclined plate for the smoke generator, and a heat generator(<Figure 2>). The smoke's flow rate was 18.1m3/h and the heat source was 54.5kW. Camera were standing on the 1st, 2nd, 4th, 6th, and 8th floors to capture the nature of the crowd exiting out of the building. The procedure was as follows:

① Start the heater using LPG(Liquid Propane Gas) to heat the inclined plate.
② Start the smoke machine, running its smoke through the inclined plate. This location is considered the smoke's source point.
③ Smoke detectors go off after 30 seconds.

④ Building occupants begin to evacuate.
⑤ The cameramen record the progress of the occupants′ escape.

3. The evacuation simulation

For this project researchers utilized SIMULEX, a popular two-dimensional evacuation analysis program. Researchers also considered the psychological and behavioral aspects of the subjects reacting to the fire[4].

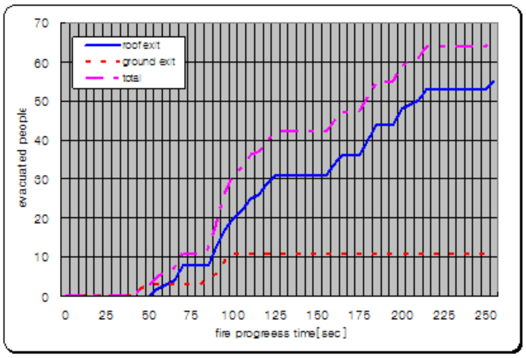
III. DISCUSSIONS OF EVACUATION EXPERIMENT AND SIMULATION

1. The experimental result

<Figure 3> shows how long it took occupants to escape after the smoke alarms sounded. The blue solid line represents occupants escaping through the roof exit the red dotted line represents those escaping through the ground floor exit the purple point chain line represents a combination of the first two. The first occupant to escape took 43 seconds after fire alarm and was from the 2nd floor.

Due to his close proximity to the ground floor exit, this occupant was only slightly exposed to the smoke. Within 96 seconds of the alarm going off all occupants who headed for the ground floor exit had escaped. It took 53 seconds for the first occupant(living on the 10th floor) to escape through the roof exit.

For the 23 occupants living between the 4th and 9th floors, it took from 90 to 125 seconds to make it through the same exit. During this time the smoke became dense. To lower their exposure, occupants naturally moved very quickly. The last occupant through the roof exit, a female, took 254 seconds and arrived via the longest path from the 3rd floor. <Figure 4> illustrates to some degree how difficult it was to navigate through the smoke, which significantly impeded the evacuation time.

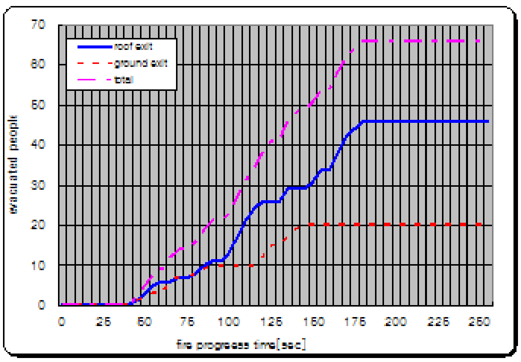


<Figure 3> The Number of People of Escaping by Time

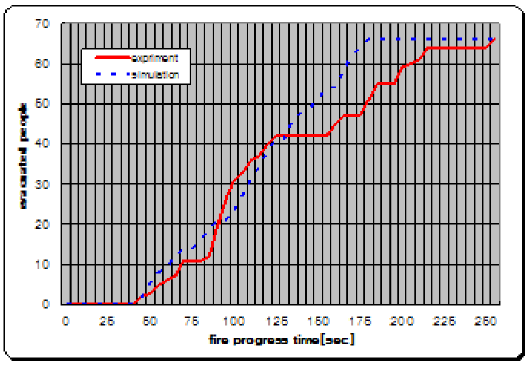
<Figure 4> The lack of Visibility Due to Thick Smoke at Roof Exit

2. Results of the evacuation simulation

The simulation was conducted under the same conditions as the actual experiment. <Figure 5> shows the time it took the simulated occupants to escape from the time the alarm sounded. In the simulation, second floor occupants escaped in 45 seconds; third floor occupants, exiting through the roof, escaped in 180 seconds. This correlates to the experiment in terms of distance from the source. In terms of how the occupants escaped, the simulated occupants escaped at a steadier pace. The simulated visibility and speed of escape were similar to the experiment. While researchers could not expect the quantities to be consistent, the qualitative tendency was the same.



<Figure 5> The Number of People Escaping According to Fire Progress Time



<Figure 6> The Accumulated Number of Evacuees between Evacuation Experiment and Simulation

3. Comparisons between experiment and simulation

<Figure 6> compares the simulated number of occupants escaping and the speed of their escape. The blue solid line represents occupants escaping through the roof exit the red dotted line represents those escaping through the ground floor exit the purple point chain line represents a combination of the first two.

The figure shows the evacuation time to be consistent between the experiment and the simulation. Up to 130 seconds the simulation is similar to the experiment. After that point, however, and up to 225 seconds there was a maximum difference of 10 people between simulated and actual experiments. This is most probably due to the stress the actual occupants dealt with, an effect absent from the simulation. Future research on evacuation could focus on such elements as human visibility and breathing capabilities. Such efforts might produce results that resemble more closely those from the experiment.

Ⅳ. THE SMOKE MOVING SIMULATION

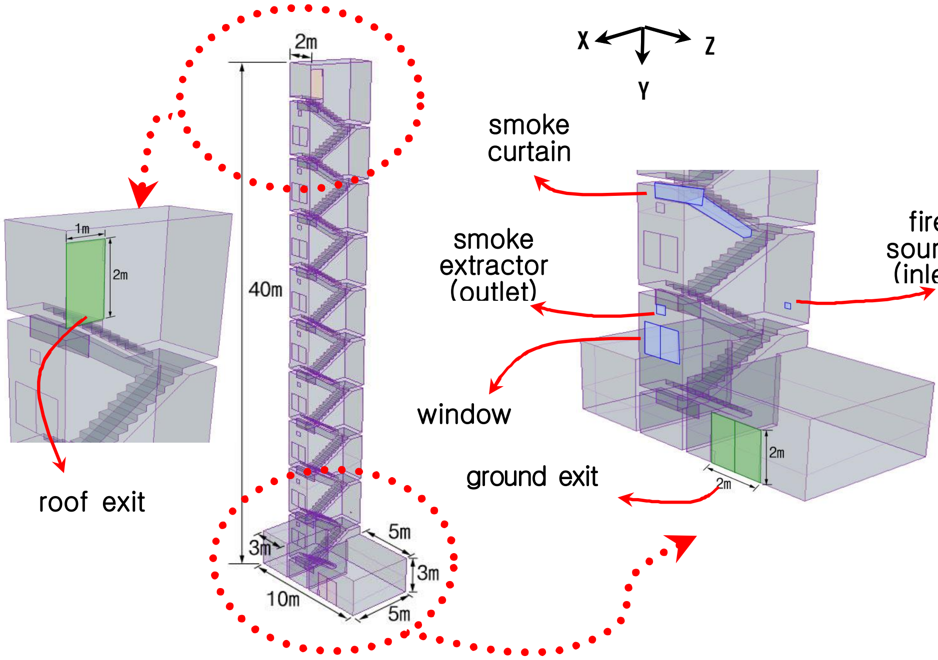
1. Numerical modeling

As mentioned earlier, the model for the simulation was based on the building where the actual experiment was conducted. <Figure 7> shows the model's specifications. The building's height is 40m and the fire protection curtain's height is 0.6m [5]. The ground floor exit is 4m2(2.0m × 2.0m), and the roof's exit is 2m2(1.0m × 2.0m). For parameters, three cases were selected(an ordinary unequipped stairwell, one equipped with an exhaust fan and one equipped with a fire protection curtain). All three are displayed in(<Table 1>).

<Table 1> Initial and Boundary Condition

	Case 1	Case 2 (with smoke extractor)	Case 3 (with fire protection curtain)
initial condition(t=0)	u=v=w=0, T=293K, C=0		
ground exit	P=294Pa, T=285.8K, C=0		
roof exit	P=0Pa $\frac{\partial T}{\partial x}=\frac{\partial T}{\partial y}=\frac{\partial T}{\partial z}=0$		
Inlet (fire source)	ms=4.89×10-3kg/s, mco=0.9 ms, T=340K		
Outlet (smoke extractor)	-	0.429kg/s at t>30s	-

2. Numerical analysis method

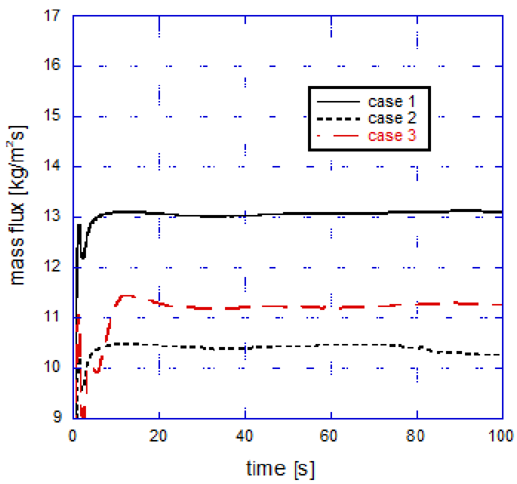


<Figure 7> The Schematic Diagram

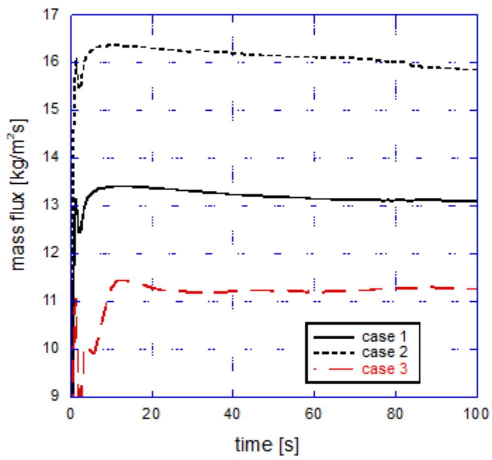
Patankar's Finite Volumetric Method[6] was used to analyze the airflow pattern, making discrete control volumes; it was solved using the SIMPLE algorithm. STAR-CD[7], a commercial CFD program, made the actual calculations. In order to calculate a convection term from the finite difference equation, an upwind differencing scheme was used. To get the velocity field, researchers made use of PISO(Pressure-Implicit with Splitting of Operators) algorithms[8]. For the simulation, there were 540,000 control volumes for Cases 1 and 2. For Case 3(the fire protection curtain), that number was 1,030,000.

V. DISCUSSIONS OF CFD SIMULATION

Researchers selected an elapsed time of about 180 seconds. <Figure 8> and <Figure 9> show the distributions of the air mass flux through the roof exit and the ground floor exit. They display the conditions of with and without the exhaust fans and the fire protection curtain. In order to show more accurate results, a time range of 0 to 100 seconds was selected to show from the beginning state to the steady state. <Figure 8> represents the mass flux distributions according to the time variance at the roof exit. In the first case(no exhaust fans or fire protection curtain), as seen in <Figure 8>, there was no air movement at the initial state. From 0 to 10 seconds, however the mass flux suddenly increased. After 10 seconds the mass flux reached the constant value of 13 kg/m2·s because of the temperature difference between indoor and outdoor, the so-called "stack effect." As far as the time patterns go, Case 2(exhaust fan on each floor) and Case 3(fire protection curtain) bore similarities to Case 1. As far as quantity goes, however, Case 1 is 2.62 kg/m2·s greater than Case 2 and 1.87 kg/m2·s greater than Case 3. <Figure 9> shows the mass flux distributions according to the time variation at the ground floor exit. The mass flux for Case 2 is 2.97 kg/m2·s higher than for Case 1. It is also 4.87 kg/m2·s higher than for Case 3. In Case 2, by dint of the stack effect(caused by temperature differences between indoor and outdoor air) and the ten exhaust fans, the indoor air is forced out. The total mass flux of the ten exhaust fans is 5.63 kg/m2·s. In Case 3, the fire protection curtain brought about a new pressure drop. The airflow dropped relative to Case 1. This kind of flow resistance delayed the smoke propagation.



<Figure 8> The Air Mass Flux Distribution According to Elapsed Time at Roof Exit

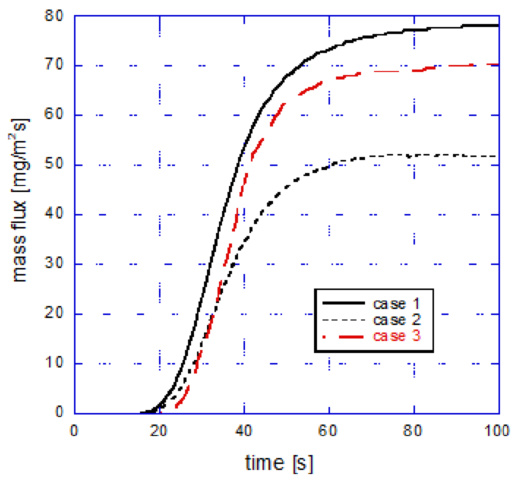


<Figure 9> The Air Mass Flux Distribution According to Elapsed Time at Ground Floor Exit

<Figure 10> shows the mass flux distribution of the CO gas according to the time variation at the roof exit for Cases 1, 2, and 3. As <Figure 10> shows, for the first 20 seconds the CO for all the cases was at almost zero mass flux. From 20 to 60 seconds the CO in all cases rapidly increased, becoming nearly constant after 80 seconds. Considering the arrival time at the roof exit of 50 mg/m2·s of CO gas mass flux, Case 1 took 38 seconds, Case 3 took 43 seconds, and Case 2 took 61 seconds. After 80 seconds all the cases reached a constant CO mass flux. For Cases 1, 2, and 3 that constant was, respectively, 78.2 mg/m2·s, 52.3 mg/m2·s ,70.5 mg/m2·s. This means Case 2 reduced the CO mass flux

33% more than did Case 1 and 9.8% more than did Case 3.

Having exhaust fans on each floor increased the inflow air at the ground floor exit by 21%.



<Figure 10> The Mass Flux Distribution of the CO Gas According to Time at Roof Exit

Ⅵ. CONCLUSION

Using the software program SIMULEX, researchers investigated how long and with what degree of safety it took residents to evacuate a ten-story building. A CFD simulation was also performed to analyze how toxic gases were propagated and to see how long it took the gas concentration to return to a steady state. There were three cases studied. The first looked at a high-rise with just an ordinary staircase. The second case involved a high-rise where each floor was equipped with an exhaust fan. The last simulated a high-rise equipped with a fire protection curtain. Researchers also conducted experimental tests to compare with results from the simulation. The final evacuee, in the experiment, reached the roof exit in 254 seconds, compared to 180 seconds in the simulation. Researchers also wanted to know the time elapsed before 50 mg/m2・s mass flux of CO flowed through the roof exit. They found that in the ordinary staircase it took 38 seconds, and in the second case, with the exhaust fans, it took 61 seconds(the best result); the fire protection curtain yielded a result of 43 seconds. The exhaust fans were capable of reducing the CO mass flux by 33% of the ordinary staircase(9.8% lower than with the fire protection curtain).

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이승철: 한양대학교에서 공학박사 학위를 취득하고(논문제목: 유동관성을 고려한 복합덕트시스템의 유량분배특성, 2000. 2), 현재 강원대학교 소방방재공학전공에서 부교수로 재직중이다. 관심분야는 터널(지하 대공간) 및 초고층 건물의 환기 및 방재설비 분야다(sclee@kangwon.ac.kr).

전계원: 충북대학교에서 공학박사학위(논문제목: "홍수유출과 수질예측을 위한 Web기반 시스템의 개발", 2004년 2월)를 취득하였다. 현재 강원대학교 방재전문대학원에서 부교수로 재직중이며 풍수해, 토석류재해, 자연재해 관리에 관한 방재분야에 관심을 가지고 있다. "산악지역돌발홍수 기준우량 결정에 관한 기초연구(2010)", "지상 LiDAR를 이용한 토석류 발생량 추정에 관한 기초연구(2010)"등의 논문을 게재한 바 있다(kwjun@kangwon.ac.kr).

전병희: 동경공업대학에서 공학박사학위(논문제목: "Study on Porous Carrier and Membrane Hybrid Process for Nitrogen Removal in Wastewater", 2000년 3월)를 취득하였으며, 현재는 강원대학교 소방방재학부 부교수로 재직 중이다. 주 연구분야는 패턴분류를 이용한 수처리장치 고장진단과 산지재해 분야이며, 현재 방재학회 회원 등으로 활동 중이다(bhjun@kangwon.ac.kr).