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지하철 터널내의 객차 화재발생시 환기실 위치변화에 따른 화재특성의 수치적 연구

Numerical Predictions of Fire Characteristics of Passenger Train Fire in an Underground Subway Tunnel, Depending on Change of Location of Ventilation Facility

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요　약

본 연구의 목적은 지하철 터널에서 화재가 발생한 경우 역사와 환기실의 위치에 따른 화재특성을 수치적으로 분석하는데 있다. 이를 위해 피난거리, 피난시간 및 최악조건 화재가 발생한 2가지 시나리오를 선정하고, 환기실 위치 변경에 따른 시간별 화재상황에 대한 터널내의 시류 및 열환경을 분석하였다. 화재해석을 위해 FLUENT v.6.3.26을 이용하였으며, 난류모델은 표준 k-ε 모델을 사용하였다. 경우에 따른 터널 내 일산화탄소의 농도 분포, 온도분포 및 속도분포의 결과를 분석하였고 본 연구의 결과는 지하철 역사 및 터널 설계시 최적의 방재 및 환기시스템을 구축하는데 기여할 것으로 생각된다.

ABSTRACT

The study is to perform numerical analysis of train fire characteristics in an underground subway tunnel, depending the different locations of ventilation facility. To study the characteristics of train fire, two kinds of worst-case scenarios are selected, based on escape distance, escape time, and fire zone, and trends and thermal environments of tunnel are analyzed by changing the locations of ventilation facility for times. Fire characteristics is calculated by using FLUENT v.6.3.26, and turbulent flow is calculated by using the standard k-ε model. The numerical results show distribution of carbon monoxide concentration, temperature, and velocity. The results of this study will contribute to building the most suitable ventilation systems when designing subway stations and tunnels.

Keywords : Numerical analysis, Train fire, Underground subway tunnel

1. Introduction

As the population density in large cities is getting higher and the traffic volume increases continuously, the roads can not accommodate such traffic increase any more so that construction of new subways or extension of existing subways are constantly going on. In Korea, the risk of subway fire has been widely recognized since fire took place at the Daegu Jungangro Subway Station in 2003.

Because most subway stations are still poorly guarded against the danger of fire or terror attacks, it is necessary to set up substantial prevention measures against any possible fire or terror attack. It may be the most ideal way to set up several countermeasures through real fire experiments in a real subway station or tunnel or at an experimental space of equivalent environment, but there are many risk factors when setting fire in an actually operating or under construction subway station or tunnel. Therefore, many researchers use estimation methods through fire experiments of heat buoyancy models and reduced range of experiments, as well as CFD.[1-8] In case of fire, most ventilation rooms, which influence development

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of fire and spread of heat and toxic gases a lot, are far away from the station building, and this may interrupt fast response to emergency cases and restrain proper maintenance. Therefore, to respond to such problems, the current new subway stations are designed to be connected with the ventilation rooms to respond faster to various situations. Therefore, in this study numerical analysis was conducted on a case where a running train was caught fire and stoped in the middle of a tunnel to estimate fire characteristics according to change in the location of the ventilation room by connecting the subway station and the ventilation room to build an optimized fire prevention and ventilation system when designing a subway station or a tunnel. To analyze fire characteristics, two scenarios on the worst fire conditions on available escape distance and time were selected and trends and thermal environments at the tunnel were analyzed at each time when fire developed.

2. Computer Fire Simulation

2.1 Summary of Subway Tunnel

In this study, the subway station and the tunnel of the Seoul Metro were modeled. The tunnel distance to be analyzed was 1,770 m long between two station buildings and a train (4.5 m(W)×19.5 m(L)×3.4 m(H)× 10 (vehicle)) was selected. Figure 1 shows an overall diagram of the analysis subject and change in the location of the ventilation room. The worst-case scenarios are seen in Table 1, considering the reaction distance, escape distance and smoke diffusion. Figure 2 shows the normal ventilation mode and the ventilation mode according to the fire location of the worst-case fire scenarios, which were taken into account for this numerical analysis.

Table 1. Worst-case scenario

Scenario	Maximum Escape Distance	Worst-Case Smoke Dissipation, Escape Distance, and Smoke Control
Train Progress	Station A	Station B
Stop Location	Ventilation No. 2	Ventilation No. 4
Fire Location	1st Cabin	1st Cabin
Escape Direction	Stop B	Stop A

2.2 Analysis Program

The software used in this study is FLUENT (version 6.3.26)[4] developed by ANSYS. INC in the USA and useful to analyze 3D or 2D flow velocity, distribution of temperature, pressure and density, which cannot be identified with 1D flow analysis since it is 3D flow analysis code, simulating flow movement and heat transmission in various shapes of models. With this

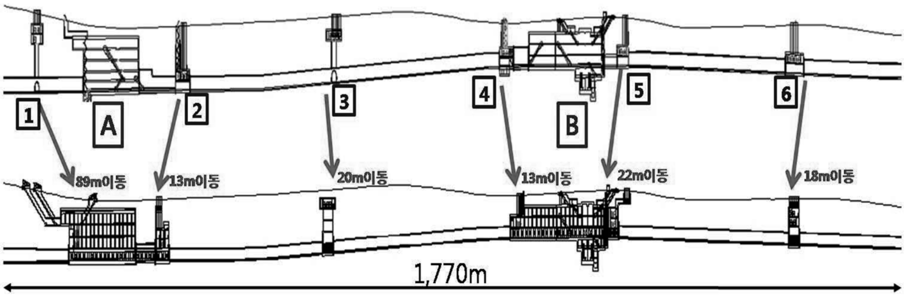


Figure 1. Analysis schematic and movement of ventilation facilities.

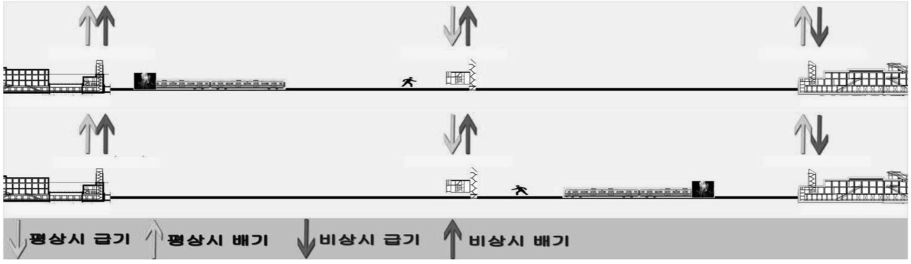


Figure 2. Tunnel ventilation of the general and emergency mode.

software, it is possible to realize an accurate geometric shape by receiving information prepared in other CAD programs and it is also possible to make precious modeling by using complicated grids of structured or unstructured tetrahedron and hexahedron.

It is possible to analyze the flow within 2D/3D shapes by using complicate grids such as unstructured triangle/tetrahedron, rectangular/hexahedron, prism (trigonal prism) and pyramid and also possible to analyze various phenomena such as compound and chemical response of chemical materials and burning/surface pigmentation models. Therefore, it is used for the construction sector such as architecture, civil engineering and plant by many domestic/international corporations and various road and tunnel projects and subway design areas as well as microanalysis on structures and air flow applied to ships, vehicles or airplanes.

2.3 Method of Numerical Analysis

The boundary conditions of fire simulation are as follows. In 3D transient state, the initial temperature inside the tunnel was set at 27°C and that outside the tunnel was set at 23°C. The pressure was set at atmospheric pressure (101,325 Pa) and the gravitation acceleration was set at 9.81 m/s^2. Standard k-ε Model of non-compressed abnormal air was used for the turbulent model[10].

$$\frac{\partial \rho k}{\partial t}+\frac{\partial}{\partial x_j}(\rho v_j k)=\frac{\partial}{\partial x_j}\left(\frac{\mu_e}{\sigma_k}\frac{\partial k}{\partial x_j}\right)+G_k+G_b-\rho\varepsilon \qquad (1)$$

$$\frac{\partial \rho \varepsilon}{\partial t}+\frac{\partial}{\partial x_j}(\rho v_j \varepsilon)=\frac{\partial}{\partial x_j}\left(\frac{\mu_e}{\sigma_\varepsilon}\frac{\partial \varepsilon}{\partial x_j}\right)+C_1\frac{\varepsilon}{k}G_k-C_2\rho\frac{\varepsilon^2}{k} \qquad (2)$$

In these equations, k and ε are the turbulence kinetic

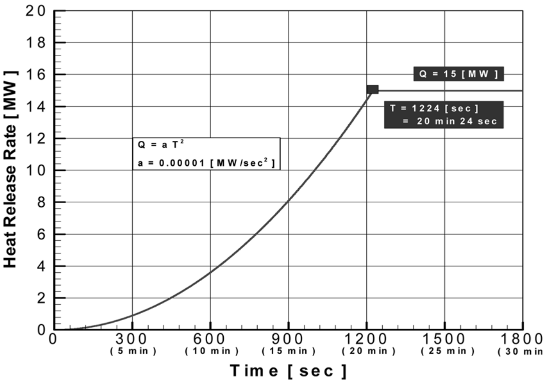
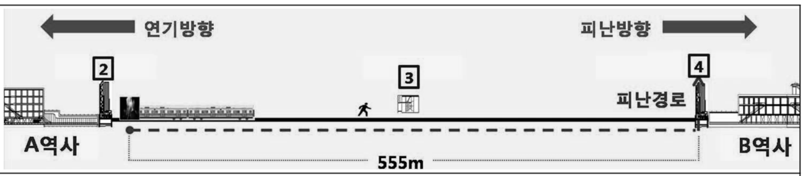
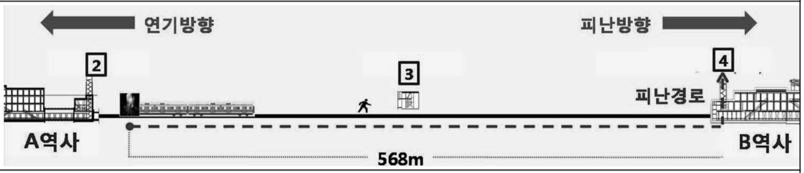
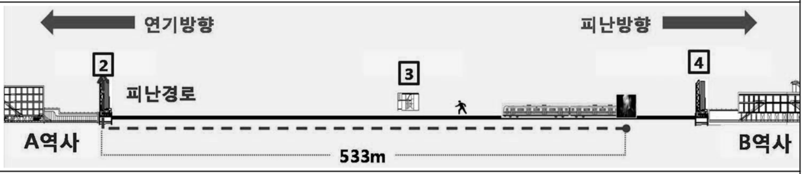
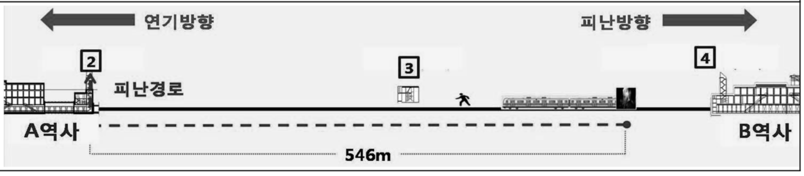


Figure 3. Growth of fire.

Table 2. Conditions for numerical analysis

Case1	
Case2	
Case3	
Case4	

energy and its rate of dissipation. G_k and G_b represent the generation of turbulence kinetic energy due to the mean velocity gradients and buoyancy. C_1 and C_2 are constans.

It was set that fire took place at a passenger vehicle (the first cabin to the train movement direction) under the worst condition considering the available escape distance and time, and the maximum caloric value 15 MW was designated according to the demonstration results conducted in Europe. In the demonstration, an actual German IC train vehicle (steel vehicle) was used, and its material (stainless steel) was similar to domestic subway vehicles. It was set that it took 1,224 seconds for fire to reach its maximum caloric value after fire occurred and thermal units generated over time are shown in Figure 3, using the formula of Power Law Relation[11)].

For the worst-case scenarios on the moving vehicles to each station building, the introduction of the analysis subject, smoke direction, and evacuation direction are shown in Table 2 according to change in the location of the ventilation port.

3. Numerical Result and Discussion

3.1 Distribution of CO Concentration Inside Tunnel

When it reached about 150 seconds after fire, a back current was not generated because of air inertial force due to traffic ventilation force generated from the beginning of fire. In the initial stages of fire development, there was low fire caloric value and smoke, and any back current was not generated because of the air current generated by machine ventilation inside the tunnel and the air current by traffic ventilation force. When it reached 300 seconds after fire, any back current still was not generated because of air inertial force due to traffic ventilation force even though CO moved to the vehicle movement direction along the tunnel ceiling. This phenomenon continued until 600 seconds after fire but, relatively a lot of CO gas began to appear to the vehicle movement direction. It is found tat when it reached 1,200 seconds after fire-the time when the fire caloric value and the smoke amount reached their maximum value, a back current took place to the evacuation direction along the tunnel ceiling due to a rising current of air caused by buoyancy as fire caloric value increased in Case 1 while the smoke control device running at Ventilation Room 1 and Station Building A railroad prevented a back current from taking place in Case 2. After 1,800 seconds, a back current took place in Case 1-a case of fire around Station Building A and it is evaluated that this was because the location of Ventilation Room 1 was about 90 m farther in Case 1 than in Case 2. It is found that the smoke control device running at Ventilation Room 1 and Station Building A railroad prevented a back current due to buoyancy effect from taking place in Case 2. In Case 3 and Case 4, a smoke control device of 4,000CMM exclusive for Ventilation Room 4 was installed for better smoke controlling and as a result, a back current was not generated for the simulation time (1800 seconds). Figure 4 shows the distribution of CO concentration and graph when it passed 1200 seconds after fire took place.

3.2 Distribution of Temperature Inside Tunnel

When it exceeded 150 seconds after fire, any back current was not generated because of air inertial force due to traffic ventilation force from the beginning of fire and a rising current of air caused by buoyancy and temperature spread showed a little because fire was not well developed. After it passed 300 seconds after fire, heat air current diffused to the vehicle movement direction along the tunnel ceiling and even it passed 600 seconds, there was no heat current diffusion to the evacuation direction caused by a back current because the smoke current fan ran. When it reached 1,200 second, a back current took place along the tunnel ceiling to the evacuation direction because of a rising current of air caused by buoyancy as the fire caloric value increased in Case 1 but, there was no back current in other cases. When it passed 1,800 second, a back current took place in Case 1-a case of fire around Station Building A and it is evaluated that this was because the location of Ventilation Room 1 was about 90m farther in Case 1 than in Case 2. Figure 5 shows the distribution of temperature and graph when it passed 1200 seconds after fire took place.

3.3 Distribution of Velocity Inside Tunnel

When it passed 150 seconds after fire, the flow velocity around the train caught fire appeared relatively high because of air inertial force due to traffic ventilation force, buoyancy due to fire and operation of a fire prevention system. It is thought that the air current characteristics and the smoke control effects inside the tunnel were good because the normal ventilation method of the ventilation room close to the place where fire took place and the ventilation method according to the occurrence of fire were equivalent.

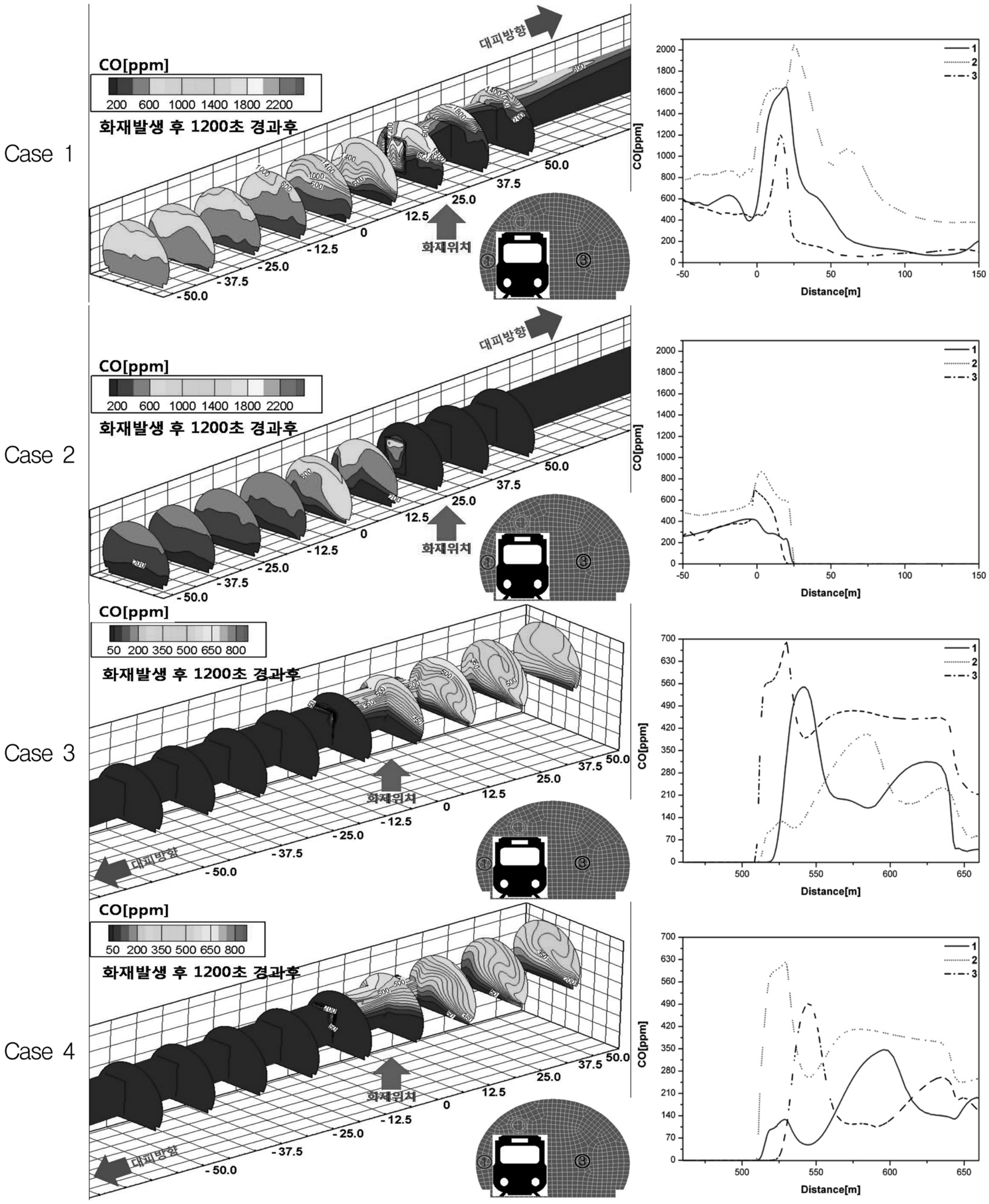


Figure 4. Comparison of carbon monoxide concentration contours and profiles at t = 1200 sec..

Because of the buoyancy effect and the influence of the fan operation in Ventilation Room 2 as the fire caloric value increased, the flow velocity between the vehicle caught fire and Ventilation Room 2 appeared relatively high when it exceeded 300 seconds after fire. In Case1 and 2, it was evaluated that the air current characteristics

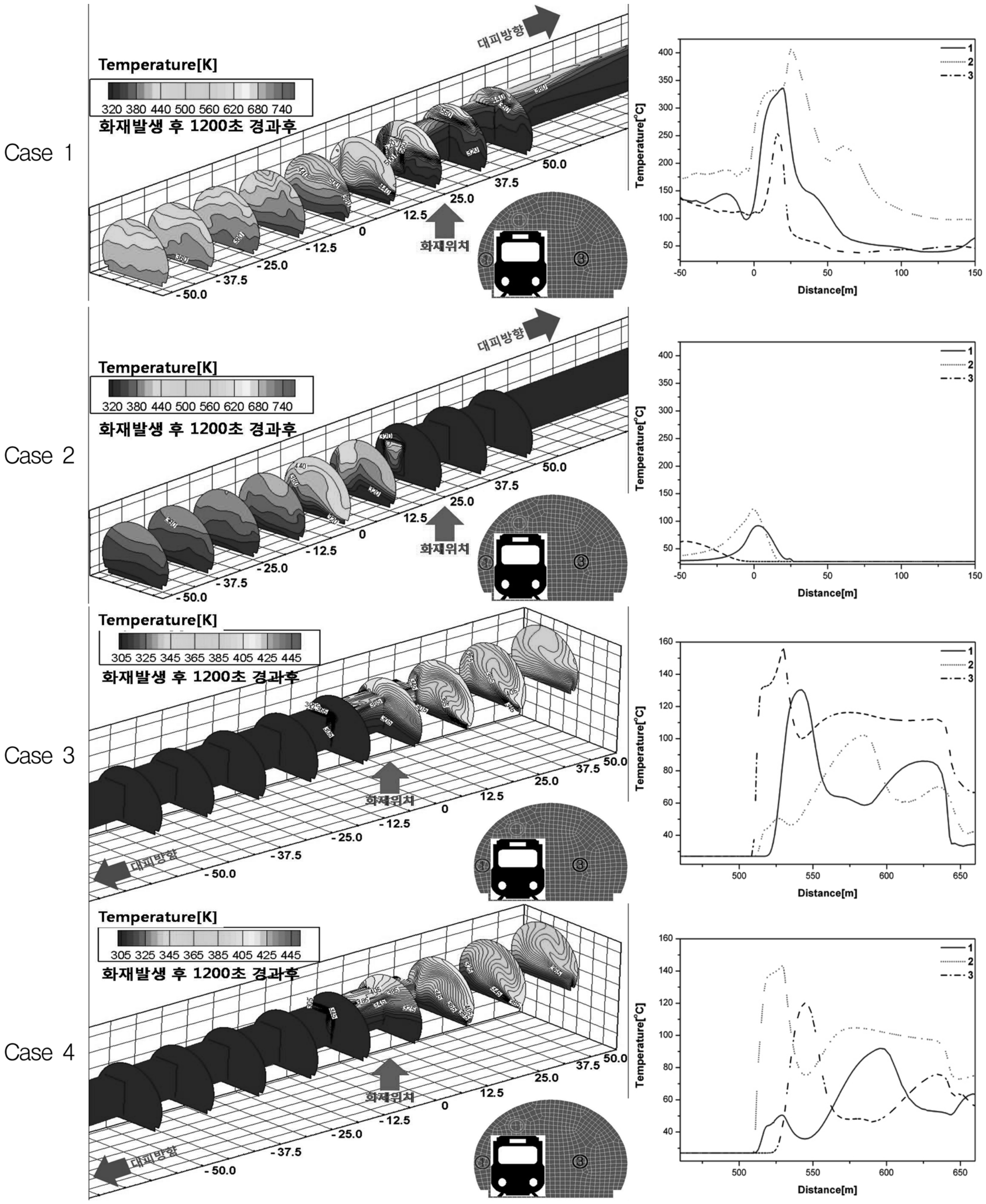
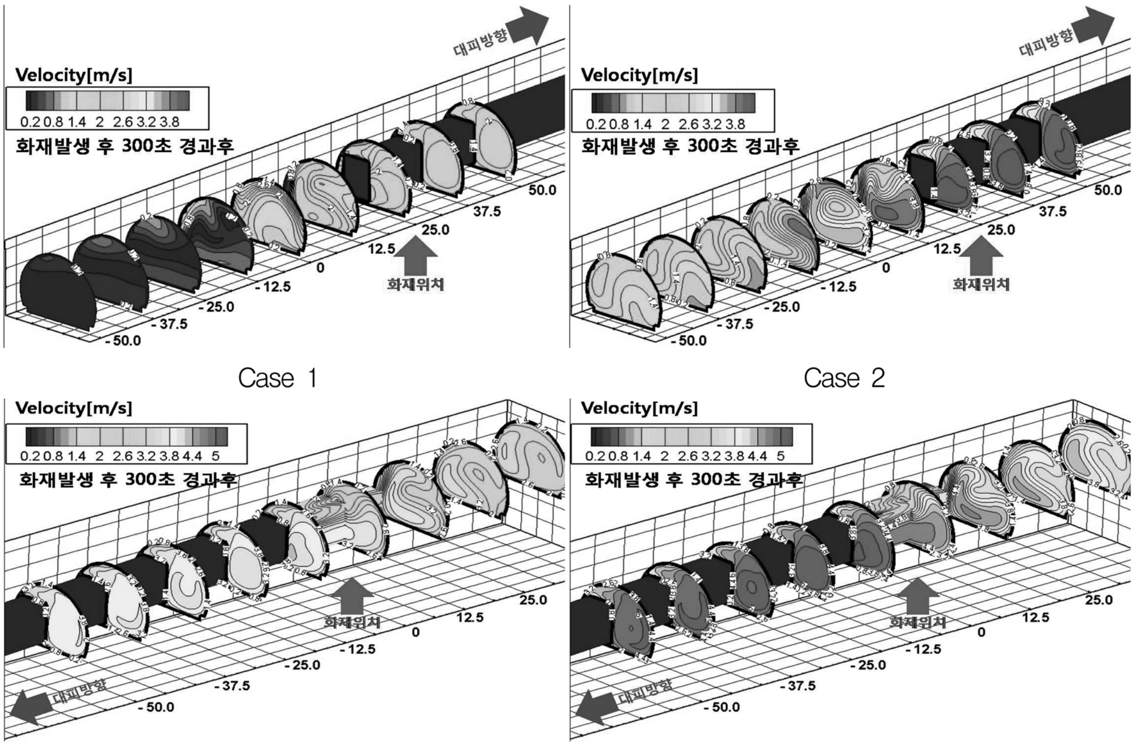


Figure 5. Comparison of temperature contours and profiles at t = 1200 sec..

and the smoke control effects inside the tunnel would be good because the normal ventilation method of the ventilation room close to the place where fire took place and the ventilation method according to the occurrence of fire were equivalent. In Case 3 and 4, it appeared around the train ceiling because of the



Case 1 Case 2

Case 3 Case 4

Figure 6. Comparison of velocity contours at t = 300 sec..

buoyancy effect as the fire caloric value increased. After it passed 600 seconds, the tunnel flow velocity in the opposite railroad appeared relatively high because of the train caught fire but, the flow velocity remained constant to the opposite direction to the evacuation direction even though the caloric value increased. After it exceeded 1,200 second, the diffusion of heat air current barely appeared to the evacuation direction due to a back current because the smoke control fan was operated and the tunnel flow velocity showed relatively high in the opposite railroad because of the train caught fire. Figure 6 shows the distribution of flow velocity when it passed 300 seconds after fire.

4. Conclusion

This study anticipated fire development against the worst-case scenarios of available escape distance, tim,e and fire location in order to build fire prevention and ventilation systems when designing subway stations and tunnels. In order to analyze fire prevention, ventilation and evacuation simulation, FLUENT V6.3.26, a heat flow analysis program, was used. For boundary conditions, CFD analysis was conducted considering the wind amount applied to real subways, ventilation and smoke control method, which are actually applied or applicable to the current subway systems, fire sizes, and fire locations based on the experiments. In case that two ventilation rooms close to the subway station are installed inside the subway building, it is evaluated that it would save construction costs, and it is found that the smoke control would be improved against the heat, CO, and flow velocity generated in case of fire.

It is found that in case that two ventilation rooms close to subway stations A and B were moved to inside the subway station, the temperature of the experimental space became relatively lower than that in the existing place (ventilation room close to the subway station) and flow velocity was similar. but it became higher when the ventilation room was moved inside the station building, and the temperature inside the tunnel showed relatively low distribution throughout the tunnel.

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