Numerical simulation of smoke movement influence to evacuation in a high-rise residential building fire

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Abstract

A 20-storey fire-occurred residential building in Japanese Hiroshima was taken as an example in the paper. The smoke movement and smoke temperature field in high-rise building fires were analyzed by numerical simulation. And the influence of fire smoke on the availability of using elevator for evacuation was discussed. Finally some effective suggestions were put forward.

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Keywords: high-rise building; fire; elevator; numerical simulation; smoke movement

1. Introduction

In recent years, the number of high-rise buildings increased rapidly. While these high-rise buildings become unique view of city, its potential hazard of fire safety exposed, and the number of high-rise building fires increased gradually [1]. Currently, using stairs for fire evacuation is the main way in high-rise building, which also has been direct in one corresponding standard. However, overlong time to evacuate puts this way at a disadvantage, especially unfavorable for the old, weak, sick, disabled, children and other special groups to escape from danger speedily [2]. Recently more and more researchers [3-6] are interested in using elevator for fire evacuation in high-rise building. A series of factors such as electricity, smoke and water determine the success of this new evacuation way. Fire smoke is an extremely essential factor, because it will enter not only compartments of elevator to endanger the security of passengers, but also elevator-shaft through the stairwell or elevator shaft, and then spread from the elevator door to each floors of building [7].

A 20-storey fire-occurred residential building in Japanese Hiroshima was taken as an example in the paper. The smoke movement and smoke temperature field in high-rise building fires were analyzed by numerical simulation. And the influence of fire smoke on the availability of using elevator for evacuation was discussed. Finally some effective suggestions were put forward.

2. CFD numerical modeling

The NIST Fire Dynamics Simulator (FDS) [8] predicts smoke and air flow movement caused by fire, wind, ventilation systems, and other sources of momentum. A post-processor called Smokeview can be used to visualize the predictions generated by NIST FDS. FDS solves a form of the Navier-Stokes equations appropriate for low-speed, thermally-driven flows of smoke and hot gases generated in a fire. FDS was developed to specifically address fire-hazard scenarios. It is a finite-difference, large-eddy simulation (LES) model. Heat release from the fire is modeled via Lagrangian thermal...
elements (LTEs). The LTE is a Lagrangian particle that releases a specified amount of heat in a prescribed time and rate. In FDS, knowledge of a fire's heat release rate (HRR) history is required. The known HRR is distributed amongst a user specified number of LTEs which are introduced from the fire source at regular intervals. Each LTE induces buoyancy as it “burns out,” contributing to the flow throughout the computational domain. Smokeview visualizes FDS computed data by animating time dependent particle flow, 2D slice contours and surface boundary contours. Data at a particular time may also be visualized using 2D or 3D contour plots or vector plots.

Five scenarios, listed on table 1, were designed to discuss the influence of smoke movement on evacuation in high rise building fires. Fig 1, Fig 2 and Fig 3 are the scene of the scenarios.

3.1. Buildings

In the study, the following buildings were simulated: (1) High-rise Residential building of 20 stories, (2) Fire floor in the High-rise Residential building, (3) Two floors in the High-rise Residential building.

3.2. Fire floors

In order to discuss the influence of fire location on smoke movement in high rise building fires, two fire location were used. One is in the room farthest from the elevator and the staircase, and the other is in the room close to the elevator and the staircase.

3.3. Fire specification

For all simulations, a wood fire with a heat release rate of 5000 kW was used to represent building fire. The fire area was 9 m², 0.5 m above the floor and located at the middle of the fire room close to the elevator and the staircase.

3.4. Material properties

The ceiling, walls, and floor of the tunnel were made of concrete with the following thermal properties:

| Thermal conductivity: 1.0 W/m·K. |
| Thermal diffusivity: 5.7×10⁻⁷ m²/s. |
| Thickness: 0.1 m. |

Table 1. List of scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Building*</th>
<th>Fire floor</th>
<th>Fire location</th>
<th>Heat release rate (kW/m²)</th>
<th>Simulate time (s)</th>
<th>Total cells</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A</td>
<td>5th floor</td>
<td>The room farthest from the elevator and the staircase</td>
<td>5000</td>
<td>900</td>
<td>1000000</td>
</tr>
<tr>
<td>2</td>
<td>A</td>
<td>19th floor</td>
<td>The room farthest from the elevator and the staircase</td>
<td>5000</td>
<td>900</td>
<td>1000000</td>
</tr>
<tr>
<td>3</td>
<td>B</td>
<td>The first floor</td>
<td>The room farthest from the elevator and the staircase</td>
<td>5000</td>
<td>900</td>
<td>322500</td>
</tr>
<tr>
<td>4</td>
<td>B</td>
<td>The first floor</td>
<td>The room close to the elevator and the staircase</td>
<td>5000</td>
<td>900</td>
<td>322500</td>
</tr>
<tr>
<td>5</td>
<td>C</td>
<td>The first floor</td>
<td>The room close to the elevator and the staircase</td>
<td>5000</td>
<td>900</td>
<td>645000</td>
</tr>
</tbody>
</table>

*A—high-rise Residential building of 20 stories. 
B—fire floor in the High-rise Residential building. 
C—two floors in the High-rise Residential building with one is the fire floor.
Fig. 1. Fire scene with fire in different floor

Fig. 2. Fire scene with fire in different location
4.1. Influence of elevator shaft on smoke movement

Fig 4 shows the contrast of smoke spread between two scenes. In scenario 2, when fire occurs on higher floor of building, smoke spread merely in two upper floors and have little impact on lower floors within 900 seconds. In scenario 1, smoke had spread above the fire floor through stairs after 300 seconds, and at 400 second smoke had spread to the top floor through the shaft, and at 900 second smoke not only filled the air of the fire floor and above several floors but also spread very seriously on all higher floors of the building.

This shows that when fire occurs on relatively high floor, shaft has little impact on the smoke which will not spread downwards through the shaft. While fire floor is low in high-rise building, unsealed shaft will affect fire growth enormously, make fire spread to the top floor rapidly, shorten ASET (Available Safety Egress Time) greatly. Consequently, it is very important to prevent smoke from shaft. Positive pressure air supply and other initiative fire prevention measures should be taken to restrain fire growth.
4.2. Influence of fire location on smoke movement

The influence of different fire location on the smoke movement is shown in Fig 5. It can be seen that in scenario 3 the time of smoke spreading to the first elevator is 162.9s, and in scenario 4 the time is 130.5s. The time of smoke spreading to the second elevator is respectively 350s and 241.2s. The smoke of scenario 4 affected all the two elevators in the fire floor within 400s; at the same time, the smoke of scenario 3 just affected one. From the result, it can be known that the time of smoke spreading to the elevator and staircase in scenario 4 is shorter than scenario 3. Then ASET is shorter, which seriously threaten people's evacuation.

It can be known from above discussion that the fire location has a great influence on the smoke spread. So to the calculation in future, it must be studied further on how to design fire scenario and how to select the appropriate fire location.
4.3. **Influence of staircase on smoke movement**

Fig 6 shows the movement of the smoke spread through the staircase. When the smoke spread to the staircase, it spread rapidly to upper floor through the staircase. From the figure it can be seen that the smoke settling velocity in the upper floor is almost equal to the velocity in fire floor. Especially in the area around staircase, the smoke settling velocity is very fast. So it can be known from the calculation that the smoke will seriously threaten people's evacuation from the staircase if there is no smoke prevention facility in the staircase.
4.4. Influence of temperature on evacuation

In high rise building fires, the smoke temperature and wall temperature also can threaten people's evacuation and the normal operation of elevator. Here taking scenario 4 as an example, the variation trend of the smoke temperature and wall temperature around the elevator and staircase is calculated by FDS, shown in Fig 7 and Fig 8.

It can be seen from figure 7 that the wall temperature around the elevator and staircase got high with the smoke spreading to the area. When the time is 600s, the wall temperature in this area exceeded 60°C, and when the time is 900s, the highest wall temperature exceeded 200°C. However the wall temperature near the elevator door is within 60°C, which has small influence on the operation of elevator. Of cause, the result is obtained on the base of the designed fire size.

It can be seen from figure 8 that the smoke temperature near staircase exceeded 60°C when the time is 300s. And when the time is 600s, the high temperature smoke spread around the staircase. The smoke temperature near staircase exceeded 100°C, which seriously threaten people's evacuation through the staircase.

Fig.7. Variation trend of wall temperature near the staircase and elevator
5. Conclusions

(1) When fire occurs on relatively high floor, shaft has little impact on the smoke which will not spread downwards through the shaft. While fire floor is low in high-rise building, unsealed shaft will affect fire growth enormously, resulting in that fire spread to the top floor rapidly, and shorten ASET (Available Safety Egress Time) greatly. Consequently, it is very important to prevent smoke from shaft. Positive pressure air supply and other initiative fire prevention measures should be taken to restrain fire growth.

(2) When the time is 900s after fire, the wall temperature near the elevator door is within 60°C, which has small influence on the operation of elevator. Of cause, the result is obtained on the base of the designed fire size. More experimental study and numerical simulation need to be made to validate the result.

(3) When the smoke spread to the staircase, it spread rapidly to upper floor through the staircase if there is no smoke prevention facility in the staircase. And when the time is 600s, the smoke temperature near staircase exceeded 100°C, which seriously threaten people's evacuation through the staircase. So the smoke prevention facility must be installed in the high-rise building and work efficiently.

Acknowledgements

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References