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Experiment and Simulation Study on High-rise Student Apartment Fire Personal Evacuation in the Campus

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Abstract

The paper sets an evacuation scene and evacuation parameters at the actual situation in case of high-rise student apartment fire, applied BuildingExodus Evacuation Model software, and calculated the dynamic changes of evacuation time and evacuation amounts of people in each access of the building, which accords with the result of fire evacuation drill. It is concluded that it is reasonable and practicable using model software to simulate evacuation time for each floor, and the result can be a substantial reference for actual evacuation time in case of fire.

Keywords: personal evacuation model;building fire; numerical simulation; evacuation time

1. Introduction

With the rapid development of economic construction and sharp increases of material wealth, large-scale and ultra large buildings have emerged unceasingly, therefore the potential safety hazards are increasing constantly. Fire is one of the most common hazards which seriously harm people's lives and property and directly influences economic development and social stability. High-rise fire evacuation is directly related with people's life safety, and how to effectively prevent and reduce the casualties, especially group casualties, in case of fire has become an emphasis and hotspot of domestic and overseas public safety study at present. However, high-rise student apartment fire, with features of large student amounts, living centralization and big chances of fire, therefore is likely to cause great economic loss, significant casualties and substantial social influences[1]. For this purpose, this paper addresses actual situation of campus and student apartments of some university in Beijing and develops the experimental and numerical simulation study of safety evacuation.

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2. Evacuation model and building simulation

2.1. BuildingExodus evacuation model

This paper applies BuildingExodus model software to simulate people evacuation in case of high-rise student apartment fire. This software is developed by Galea of the University of Greenwith and has fine grid model for evacuation simulation [2] [3]. The model is designed for large space and large amounts of people to escape, and it is applicable for simulation of supermarkets, hospitals, cinemas, stations, airport terminals, dangerous buildings, schools and so on. It can present more practical evacuation simulation results by inputting evacuation factors including various behavior characteristics(such as physical, psychological, behavior attributes of evacuation people), and fire hazardous features(such as hazardous attributes of heavy smoke, temperature, poison gas). Therefore, the evacuation simulation results by using BuildingExodus model with evacuation situation analysis and factors setting can be an important reference for actual evacuation time in case of fire, and has a high value of development and popularization.

2.2 Basic layout of the building for numerical simulation

The building is located in Student Apartment 5# of some university in Beijing. The total area is about 20247.64m^2(excluding second basement), in which the above ground GFA accounts for 18836.30m^2， the below ground GFA accounts for 1411.34m^2; The height is 38.20m, each floor is 2.8m, the rise of stair is 14cm, and the run of stair is 30cm. This project is in type II civil architecture, 12 floors above the ground, 2 levels of basement. Above the ground is student apartment with the roof as the lift motor room; the first basement is bicycle garage and the second basement is bicycle garage and equipment room. The fire-resistive grade of buildings is Grade 2 for the above and Grade 1 for the below. The architecture is in type of reinforced concrete shear wall, and the base is foundation settlement. Each floor and stair hall is a fire zone, the first basement is divided into 3 fire zones and the second basement is divided into 4 fire zones. The plane structure of ground floor is as shown in Fig. 1(a), and the plane structures of 2-12 floors are the same as shown in Fig. 1(b). There are 3 staircases in the building for students to use including the left(Staircase 1), the right(Staircase 2) and the middle(Staircase 3); and accordingly there are 3 emergency exits on the ground floor including the left(South Exit), the right(North Exit) and the middle(Central Exit).

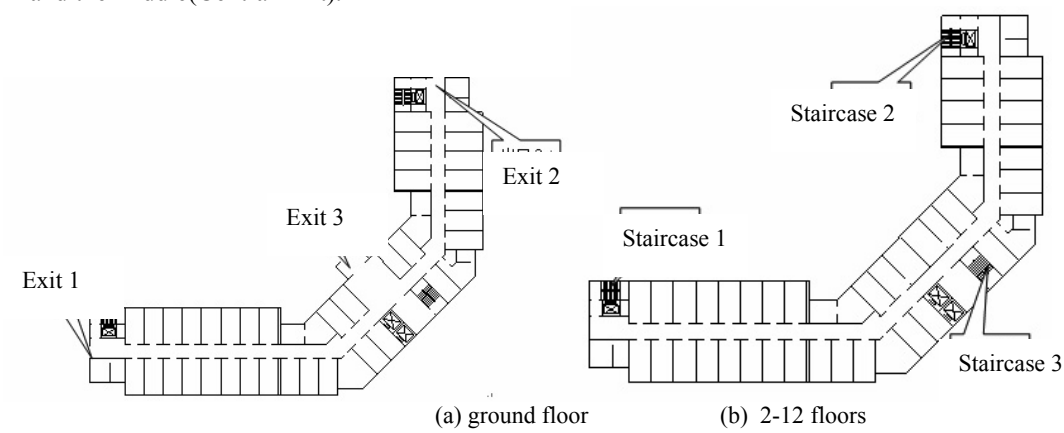

Fig. 1 Plane structure layout of the building

3. Building fire evacuation simulation experiment and parameters setting

3.1. Evacuation scene design

Fig. 2 Simulation experiment of the floor on fire

The building fire is set to break out in the 7th floor, as shown in Fig. 2. Following the rule of first evacuation from the floor on fire then alternately from the floors below and above, therefore the evacuation sequence is 7, 6, 8, 5, 9, 4, 10, 3, 11, 2, 12, 1. The evacuation is conducted with broadcast by Fire Control Center to gather together at the designated site after evacuation. Six guiding students are selected for each floor(wearing the armband showing floor number and sequence number), and disposed averagely at "North, Center, South" areas, in which one person is obliged to guide the evacuation at the head of the queue and the other followed the tail of the queue to ensure the whole students of each area evacuated. Guiding students of each floor should start to guide the evacuation as soon as hearing the broadcast of fire protection or being informed by staff. After guiding others out of the building, all the guiding students are to report to staff (wearing armbands) at the gate.

3.2. Evacuation parameters setting

(1) Evacuation direction

Emergency exits are selected according to the shortest path strategy, and evacuation direction is shown as Fig. 3. When informed of evacuation, people in the building should escape from room to the escape corridor, then to the emergency staircase, and follow the staircase to emergency exits of the building.

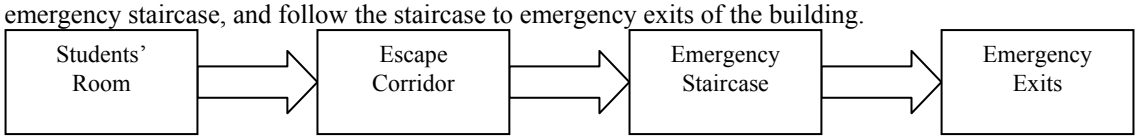

Fig. 3 Evacuation direction in case of fire

(2) Evacuation options

Assume all people in the building are informed of evacuation at the same time and take actions as soon as being informed. The evacuation time is to be calculated according to total amounts of people, numbers of floors and width of the building after setting parameters at the exits of the building. The evacuation strategy is set as including emergency escape, shortest path decision, pre-action time and so on.

(3) Grid meshing

The grid meshing is conducted according to the demand of BuildingExodus model. As the type of grid node includes free node, staircase node, interior exit and exterior exit, the staircase entrance and corridor are set as interior exits and the three accesses exterior exits.

(4) Initial people distribution

Individual types are considered of different genders, ages and items brought with. Different types of individual result in different parameters such as response time, occupying space, motility and movement velocity [4]. Fig. 4 shows people distribution of the building at initial time, and its green dots represent distribution of people. The statistical results of people in the building are shown in Table 1.

Table 1 Statistical results of people in the building

Floor	Number of rooms	Occupant density/persons per room	Number of people	Floor	Number of rooms	Occupant density/persons per room	Number of people
12th	41	6	246	6th	41	6	246
11th	41	6	246	5th	41	6	246
10th	41	6	246	4th	41	6	246
9th	41	6	246	3rd	41	6	246
8th	41	6	246	2nd	41	6	246
7th	41	6	246	1st	38	6	228
Total				2934			

(a) People distribution of the ground floor (b) People distribution of 2nd-12th floor

Fig. 4 People distribution of the building

(5) Evacuation strategy setting and path selection.Evacuation strategy is set as Evacuation Conditions, and its options are set as: local potentials, NOT extreme behavior, patient, instant response, seat jumping, stair packing, local fam.main exits and so on [5]. The initial movement direction of the building is from higher potential zones to lower potential zones.

4. Results analysis of evacuation simulation

4.1. Data analysis of simulation with BuildingExodus model

(1) Simulation results of evacuation time

According to the layout of evacuation in case of building fire, it is calculated to take 1457s to complete the evacuation. It takes 14s for all people in the floor on fire to evacuate from rooms after the command. And the 14s is the rooms clear time of the floor on fire. It takes 84s for all people in the floor on fire to evacuate from rooms and

corridor to the staircases. And the 84s is the floor clear time of the floor on fire. At this time, the fastest people have gone out of the building. And after 1408s, as people of other floors have evacuated into staircases, the last floor(the ground floor) begins to evacuate.

(2) Number of people evacuated from each access of the building and time counting

According to the dynamic changes of number of people from 3 accesses of the building, it is concluded that: Number of people evacuated from access 1 is 1007, the total evacuation time is 1457s; Number of people evacuated from access 2 is 969, the total evacuation time is 1440s; Number of people evacuated from access 3 is 862, the total evacuation time is 1382s. In the view of the whole evacuation process, it is not until 90s that some people have evacuated from accesses to safe area. Besides, the simulation results show that between certain periods of time no person evacuates from any access. In conclusion, of the three accesses, access 1 accounts for the longest evacuation time as 1457s, therefore it is the evacuation time of the whole building.

(3) Total number of people evacuated from the building and time counting

According to the dynamic changes of the total evacuation rate of the building, it is concluded that people discontinuously evacuate from the building during the whole evacuation process. In the initial stage, actual number of people from each access is 0, and the whole evacuation time is 1457s. The evacuation simulation does not quite accord with the actual situation in case of fire. The evacuation rate is not so high that no congestion or "bottleneck" occurs [6]. The reason is people in the building are evacuated in sequence as for the safety of evacuation.

4.2. Contrastive analysis between simulation data and experimental data

(1) Contrastive analysis of evacuation time of each floor

Fig. 5 is the contrast between simulation results with BuildingExodus and experimental results, from which it is concluded that the two results are essentially same as for evacuation time calculation. Therefore, it is reasonable to calculate evacuation time of each floor with model simulation.

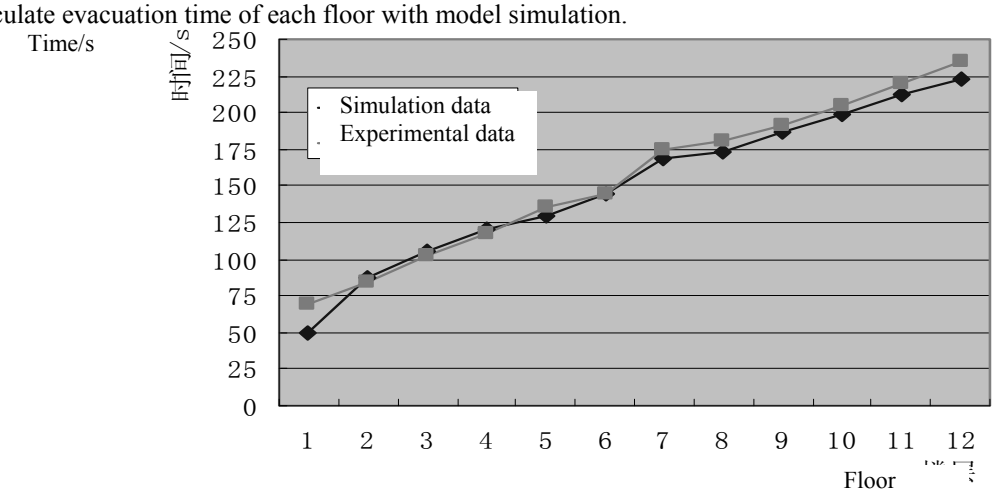

Fig. 5 Evacuation time of each floor

(2) Contrastive analysis of total evacuation time of the building

The total evacuation time of the building is measured as 1248s by experiment and 1457s by simulation, between which there is a big error. The absolute error is 209s, and the relative error is 14%. The main reasons lie as follows:

① The actual number of people in evacuation does not match that of simulation, which results in certain distortion between the two data;

② The actual evacuation may have bottleneck at some access and fluent evacuation at others, which leads to certain distortion between the two data;

③ During evacuation, students having herd mentality did not evacuate by the designate routes, which aggravates the distortion between the two data;

④ The evacuation plan did not have such a high publicity that students lay little emphasis on this drill and behaved quite at will, which brings about certain distortion between the two data.

5. Conclusions

(1) BuildingExodus model software is able to simulate evacuation of people of single attribute in multilayer buildings by reasonably defining the attributes of evacuee;

(2) After evacuation, people on the ground floor evacuate swiftly to the outer area while people of other floors immediately gather in the staircases and get blocked. The slow rate of evacuation in staircases is the main influential factor of evacuation time;

(3) The numbers of people evacuated from 3 emergency exits differ greatly and no conjunction occurs at ground evacuation exits;

(4) The reasonable placement of 3 staircases and appropriate increase of staircase width can greatly reduce the total evacuation time;

(5) The safe evacuation time can be reduced by increasing staircases and widening evacuation passageway, while these measures have some difficulty for the current structure of buildings. Therefore, it is recommended to settle sub-safe areas to alleviate the tense of the evacuee and prevent panics and congestion in the staircases.

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