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Simulation of fire and evacuation in high-rise building

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Abstract
The development of high-rise building in China is described. The high-rise building fire risk analysis is introduced, and the high-rise structural fire accident in Shanghai is analyzed. Based on the plan of Shanghai high-rise building, in this paper a high-rise building which has the same plan in a city is selected to study the movement and evacuation of it using CFAST and Building EXODUS (V40.6). The purpose of the simulation is to study the advantage and weakness of this structural form of high-rise building.

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1. Introduction

With the rapid economic development of the society, the process of urbanization is accelerating. City area is declining, high-rise buildings which cover an area with less volume rate of large features have sprung up in the city. Incomplete statistics show that in China, as of 2010, buildings more than 24 meters high-rise buildings, 9,816 in Shanghai, 7,502 in Guangzhou, 5,725 in Shenzhen, and 5,591 in Beijing, ranked respectively 3rd, 5th, 7th, 10th, and 11th in the world. High-rise buildings and super high-rise buildings has provided spacious, convenient to our working and living space, but it also have the threat of fire safety [1].

High-rise building fire spread speed, stairways, elevator shaft in high-rise building well, pipes, ducts and electricity wells of vertical shafts, if fire-resistant partition processing is not good, when the fire broke out just like a towering chimneys become ways of the rapid spread of the fire; Evacuation of high-rise building is difficult, normal elevator does not use during the fire, stairs are the only channel for vertical evacuation of persons, due to long distance of vertical evacuation of high-rise building required evacuation time longer, after the fire, as the personnel-intensive, more slow down the stairs to evacuate; High-rise building fire fighting is difficult, (the height of) high-rise buildings can be dozens of meters, even hundreds of meters, once the fire broke out from the outside, fire-fighting is very difficult, mainly because fire fighters is difficult to close the fire point, ordinary fire-fighting vehicles (are limited), at present Chinese fire-fighting vehicle has a maximum height of 101 meters, but only a few throughout the country, most of the trapped personnel based on the self-help[2].

More and more attention is paid to high-rise building fire protection safety and fire safety evacuation. Study on evacuation of high-rise buildings, to improve the safe evacuation of high-rise building performance and reduce casualties caused by the high-rise has strong realistic significance [3].
2. Description of Shanghai high-rise structural fire

Shanghai high-rise residential building construction without a license violation in the fire building 10 rooms north out of the window before the combination of layers concave gallery southwest corner, landed during the welding of metal melting, ignited fire disaster by falling below polyurethane foam fragments, debris, nylon, and bamboo plates. Polyurethane foam pieces, debris after being ignited immediately aroused walls polyurethane insulation spray combustion, spread and level up very fast, causing fires. After wall surface spray of polyurethane insulation material combustion, fire quickly spread through the entire building, due to building evacuation channel is limited, main live residence of building was older retirement teachers, in the rescue process, fire ladder can not reach the top of the building, ladder plus high pressure gun only arrived two-thirds height of the building, fire was so large that helicopter aircraft cannot get near, which blocked the smooth progress of work. Finally caused 58 people deaths and 17 people were badly injured in the tragedy.

3. Fire and evacuation simulation

A fire broke out in Shanghai high-rise residential building once again reminds us of the importance of high-rise building fire protection. Because the spread of the fire was an extremely complex process, evacuation of human physiological and psychological are constantly in change, and the fire of fire spreading characteristics from outdoor to indoor, domestic code for fire protection design of study on compartment fire, evacuation simulation software development for indoor fire, this type of fire is the first domestic case. Thus, using existing flue gas simulation software and the personnel evacuation simulation software is difficult to reproduce the fire and personnel evacuation situations. According to the statistics, a fire of tall buildings in Shanghai 5–28 floor plan, 5–28 with two evacuation stairs on the north side, the staircase on the west side of front have a fire front room, staircase on the east side of the former common room before, three households in the east, three households in the west, six people through east and west, south side of the channel into the evacuations of stairs. Under 5–28 layer structure modeled on the information described in this article, select a city of a similar construction form 28-story high-rise building using flue gas simulation software CFAST and personnel evacuation software Building EXODUS (V4.06) qualitative and quantitative evaluation that consists of a corridor and staircase tower high-rise building advantages and disadvantages on the evacuation of building structures [4].

3.1 Fire simulation by CFAST

After fire occurs, due to flue gas spread of way and personnel evacuation of route is basically consistent, selected senior building of east, and west, and south three sides of corridor and the east and west on both sides of fire stairs occurs fire, flue gas most easy spread to local [5], so when in flue gas simulation CFAST, east, and west, and south of within channel, and west fire stairs and fire front room and the east fire stairs and combined room of regional respectively division; Senior buildings is characterized by separate households in each suite, each suite contains the bedroom, the kitchen, the living room is a good interval, smoke spread slowly, each suite is divided into a region. CFAST effects of zoning are shown as Fig.1.

![Fig. 1. Divided zone of assumed building for CFAST model.](image)

This article aims to introduce three kinds of fire to this smoke flow of architectural forms, and its influence on evacuation. Fire (a) as a separate research building staircase to the east on the north side of firing a fire, regardless of the other rooms caused by fire; Fires (b) for the purpose of considering all on fire in the room at the same time (that is, similar to the fire spread quickly), assuming that there is no automatic sprinkler system in the selected building; Fire (c) while considering all the room is on fire (which is similar to the fire spread quickly), assuming that the selected building has automatic sprinkler system. Results of the study are as follows.
Figs. 2–4 represent fire (a), fires (b), fires (c) under three kinds of fire evacuation stairs on either side, in the channel between smoke layer height changes with time. Studies have found that fire under the three circumstances (a) rate of fire smoke layer down slowest, fire (c) Secondly, fires (b) rate of fire smoke layer down fastest. Description shower facilities on the effects of the smoke layer height in the whole building, is added automatically after shower facilities, smoke layer falling slowly, facilitate the evacuation.

When fire happens, the direct cause of CO content is the cause of asphyxia, and Fig. 5 shows the staircase on the CO in the things and flows inside the channel. From Fig.5, we can see things on either side of the CO content of the staircase curves coincide over time, CO up to a certain level tends to balance value, indicates that the CO content in two essentially similar staircase flows, up to a certain value does not change. CO content relative to the staircase on the evacuation of two changes, increased speed and channels of CO content in rising well above the staircase on the evacuation of two of the CO content, be balanced after a certain time. Further indicates that the channel is not conducive to smoke within a narrow channel, clustered a large amount of smoke within a short time. Escape routes must pass through the channel, channel strip, such a sprinkler system was not added, people will encounter great difficulties in the process of escaping.

3.2 Evacuation simulation by building EXODUS

Building EXODUS (V4.06 version) default housing height for 2.7 meters, as fire of continued development, flue gas layer of height constantly reduced, people stand of default height for 1.7 meters, as fire constantly developed, flue gas layer constantly reduced, as flue gas layer of height reduced to default height people of 1.7 meters, people will change action state, will due to does not adapt flue gas and will change fled way, crawling forward when the smoke layer continue to lower, reduced to crawling by default height of 1 meters when gas continue to decline, also not fully evacuated, people will be faced with the risk of choking [6].

Evacuation simulation in this section of the building is a high-rise fire in Shanghai 5–28 architectural designed of the building is based on a selection of a 28 story high-rise buildings in a city. This section using personnel evacuation software
Building EXODUS (V4.06) in selected buildings added 440 people in the 1–28 layer, this real simulation of high-rise buildings. Simulation results are as follows.

Study finds that added behavior properties, selected all 440 people in the building to evacuate the needs of outdoor time is 16 minute 29.9 seconds. In 3.1 section, study on building flue gas simulation results show, when smoke layer height get fully human asphyxia of 0 m, the maximum time needed is 800 seconds, that is about 13 minutes, so after this building on fire, workers cannot completely evacuate with evacuation time available, may result in people smoke suffocation. Selected buildings have two evacuation stairs, located in the north the east and west sides respectively, before the staircase on the west side there is a fire front room, before the staircase on the east side there is a combination of a room. West side evacuation stairs corresponds to the first floor of the west exit, corresponding to the staircase on the east side is east of west exit. Study finds that evacuation of west exit, number 93 persons, who first evacuation succeeds in 36.83 seconds, and finally a successful evacuation of personnel in 978.94 seconds, average amount of evacuation of \(5.92 \times 10^{-6}\); number 347 persons evacuated from east exit, first dispersed in 46.93 seconds successfully, and finally a successful evacuation of personnel in 989.94 s, average evacuation of \(22.08 \times 10^{-6}\). Two evacuation stairs traffic diversion effect are not clear, 78.9% selection of east evacuation stairs, and only the 21.1% selection of the west exit. Reason is because as officers at each deck level shall be smoke evacuation against the wall, in the course of the evacuation, staff will select the most recent exit to evacuate. Although households are selected in the recent channel evacuation, evacuation simulation showed that after the evacuation of residents along the west side of the channel on the east wall when you reach the shared former rooms, most of the residents before they turn into the fire with room to enter the east side of evacuation staircase evacuation. Because when the west side of evacuation staircase formed after the crowded, and after an emergency, people will select the most recent export, escape in the course of staff, easy to turn into east evacuation stairs.

4. Conclusions

This article sketches the hazard of fire in China senior building of status and senior buildings, do briefly describes on Shanghai City a senior building mega fire accident, and to Shanghai City a fire senior building of 5–28 layer of architectural design form (is by east, and west, and south three side of within channel and by is located in north of two seat evacuation stairs composition of building plane) for modeled, selected a city a building senior building real, using flue gas simulation software CFAST and personnel evacuation software Building EXODUS (V40.6) to be flue gas simulation and personnel evacuation simulation, simulation advantages and disadvantages of this form of architectural plan with regard to evacuation. Come to the following conclusions.

(1) High building as the “chimney effect” flue gas to quickly spread throughout the building, especially in buildings-tower high-rise building and unit high-rise buildings such as promenade, fire, smoke will flood the promenade, and evacuation and must pass through the corridor, CO concentrations rising rapidly, people are vulnerable to suffocation.

(2) High building room gallery, such as gallery sets can effectively start the automatic sprinkler system and automatic smoke extraction system, can play to reduce flue gas temperature and slow the effects of smoke spread, extension personnel evacuation time available.

(3) Smoke-proof stairwells of high-rise building and closed staircases are usually equipped with fire doors, fire doors need to stay close, if the door does not close, not only encourage the “chimney effect”, smoke will spread easily to the fire escape stairs, obstruct the personnel evacuation of fire escape staircases.

(4) The provisions of the code for fire protection design of tall buildings, 18-storey tower high-rise buildings, two evacuation stairs should be independent of setting, when you are having difficulty, you can set the Scissor staircase. The
code for fire protection design of tall buildings on the stairs of the set location is unclear, but for high-rise building, staff capacity rate, set two stairs on one side, too close to the location, causing jams on the evacuation routes. Settings for the two evacuation stairs location from the evacuation of the perspective, can really achieve the objective of improving the efficiency of the evacuation.

(5) Human intervention is particularly important during the evacuation, evacuation of human intervention that is the boot, each floor with one quantitative evacuation guide in favor of improving utilization efficiency of two evacuation stairs, preventing panic jams, evacuation of high-rise building fire emergency exercises are beneficial to personnel ordered to evacuate.

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