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Probabilistic Model of Smoke Filling in Large Spaces

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Abstract

There are many uncertain factors to affect the process of smoke filling in large spaces. In this paper, experimental studies on natural smoke filling induced by an electric car fire were carried out to compare with the model of smoke filling in large spaces. The experimental results are in good agreement with the theoretical values. Afterwards, Latin Hypercube Sampling method was used to mathematically describe the probabilistic model of smoke filling in large spaces. Latin Hypercube Sampling method was used to carry out a computer simulation sampling of the uncertain factors in the process of smoke filling in large space. The probability density function was used to describe the randomness of the uncertain factors in the smoke filling process. Then, the Pathfinder simulation and data review, the time needed for evacuation was obtained. By comparing the difference between the time of smoke filling and evacuation, the failure probability of smoke control under the effect of uncertain factors was obtained. The probability model developed in this paper to determine the failure progress is more reasonable than the traditional method. The model is more suitable to assess the risk of large spaces building fire and can also combine with the risk tolerance to develop safety assessment.

Keywords: smoke filling, large spaces, uncertain parameters, probabilistic model

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1. Introduction

Smoke filling is an important process of fire. According to the fire cases at home and abroad, the direct death caused by smoke poisoning accounted for about 1/2 to 2/3 [1]. Because large space buildings are difficult to divide into fire and smoke partition area, fire smoke spreads rapidly to other parts of the building and it is difficult to monitor and warn the fire [2]. Only when the fire develops to a certain scale, the detector can sense it. This poses a great threat to the evacuation of occupants in buildings and the fire rescue of firefighters. Therefore, it has important practical significance to develop the probabilistic model of smoke filling in large spaces during the fire in order to predict the collapse of the structure and guide evacuation.

Huo R (2005) studied experimentally how smoke spilling out of a shop fire would fill up an atrium. He assessed two plume models of smoke spilling out of a shop fire inside an atrium and derived an equation on studying the smoke layer interface height with a two-layer approach [3]. Chow W K (2001) carried out experimental studies on natural smoke filling in an atrium induced by a liquid pool fire up to 1.6 MW to measure the fuel quality, vertical temperature distribution and smoke layer height. He found good agreement was observed by results compared with those predicted by a smoke filling model developed from plume equations, the NFPA smoke filling equation and a model developed by Tanaka. Finally, he developed a new model of smoke filling [4]. Kaye (2007) considered the smoke filling of a room from a small, centrally located floor fire. The rate at which the smoke layer deepened was shown to be more rapid for relatively wide rooms (large

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aspect ratio). However, in most times, smoke filled more rapidly in relatively tall rooms (small aspect ratio) because of large scale overturning and engulfing of ambient fluid [5].

However, in fires, smoke control involves the interaction of fire, occupants and building. In addition to the smoke filling process, the evacuation process is also very important. At present, evacuation time is mainly determined by computer simulation or evacuation experiments. Gwynne et al. (2001) developed a behaviour process model to simulate people's recognition of fire, decision making and preparing for evacuation [6]. Yi Yang(2014) developed a fire evacuation model based on cellular automata (CA) to simulate occupant evacuation behaviours in case of public place fires, which can reflect individual characteristics, herd behaviours and the environmental effects on the evacuation behaviour. Furthermore, it provided a platform for further research on fire safety evacuation in public places [7]. Wang and Lu (1993) analysed the fire in the central Twin Towers (WT1 and WT2) in New York, USA, in 1993. The results showed that the probability density function obeyed normal distribution or Webb distribution, and the fitting result of normal distribution was better than that of Webb distribution [8].

There are two characteristics of certainty and randomness in these processes. (Magnusson 1996). Ahmed. M Salem (2016) explored the uncertainty of fire propagation effects through Monte Carlo simulation. The results showed that the available safe evacuation time was usually affected by the uncertain of the input data. Of all parameters, fire toxicity was the most important factor affecting safe evacuation time in all factors [9]. Zhang and Huang (2017) simulated the uncertainties in the evacuation process by the Latin hypercube sampling method and described the randomness of the uncertain factors in the evacuation process by the probability density function [10].

2. Probabilistic model of smoke filling in large spaces

2.1. Smoke filling in large spaces

The natural smoke filling in large spaces means that the smoke flow is not influenced by the outside environment and forms the smoke layer in enclosure large spaces. In enclosure fire, the development of smoke layer is usually described by two-zone model. The basic idea of two-one model is that the interior spaces is divided into an upper hot smoke zone and a lower cold air zone. The properties of each layer of gas are spatially uniform. It is supposed all the other openings in the hall are closed, leaving only a small leakage at floor level, choosing the upper layer as control volume and applying the mass conservation to the volume. Eq. (1) can be obtained to calculate the height of the smoke layer z [11-12].

$$z=\left(\frac{0.21}{\rho_g}\left(\frac{\rho_a^2 g}{C_p T_a}\right)^{1/3}\frac{\alpha^{1/3}}{S}\frac{2t^{(1+n/3)}}{n+3}+\frac{1}{H^{2/3}}\right)^{-3/2} \tag{1}$$

Where, α is related to the speed at which the fire develops, ρ_g is the density of the upper smoke layer, C_p , T_a , ρ_a are specific heat, temperature and the density of the air in the outdoor environment. S , H are the floor area and the ceiling height of the building, t is time, n obeys $\dot{Q}=\alpha t^n$, $\dot{Q}$ is the heat release rate of fire.

2.2. Validation test of smoke filling model

The purpose of smoke filling experiment is to determine the relationship between smoke height and time. Comparing the experimental result with theoretical value to verify the rationality of the model. The experiment site is showed in Fig. 1. Due to the space in the experimental hall is very large, oxygen consumption calorimeter can't be used on this system. The experimental fire source has great mass and the fuel species are too complex to calculate the heat release rate by the mass loss method. Therefore, a heat flow meter was installed at 4 m distance from the fire source, and the heat release rate of the fire source was calculated by using the radiation heat flow. The radiation heat received at r m from the fire center can be calculated from the heat release rate of the fire source, as shown in the Eq. (2).

$$\dot{q}_f=\frac{\chi\dot{Q}}{4\pi r^2} \tag{2}$$

Where, $\dot{q}_f$ is the radiation heat flux received at r m from the fire center, χ is radiation coefficient, $\dot{Q}$ is heat release rate of fire, r is the distance between a point in space and the fire center.