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Fire risk assessment for large-scale commercial buildings based on structure entropy weight method

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ABSTRACT

Based on the fire characteristic and the maintenance of fire equipment in the large-scale commercial buildings, this paper proposed a fire risk assessment system for large-scale commercial buildings. The assessment system focus on evaluating the safety performance of the fire protection system in the buildings. Firstly, the index system of the assessment system was determined by on-site investigation and experts' suggestions. Secondly, the weight of each index was determined by the structure entropy weight method. Thirdly, the score rules were determined according to the regulations from the relevant laws and design codes. Finally, the score and the corresponding fire risk level could be obtained. Moreover, four large-scale commercial buildings in Chongqing, China have been taken as examples to calculate the values of the fire risk level by the proposed assessment system. In addition, the fire safety performance of the four buildings were analyzed.

1. Introduction

With the continuous development of China's economic and acceleration of urbanization, people's living standard is being improved, the requirements on the level and environment of the shopping mall is being raised, hence a lot of large-scale commercial buildings are being constructed. As a comprehensive entertainment center, the large-scale commercial building has the features of large scale, atrium inside and multiple functions, it usually combines restaurant, leisure, tourism, residence, finance, culture, art, etc.

The large-scale commercial building is defined as any floor area of the building is equal or greater than 5000 m^2, or the total area is equal or greater than 15,000 m^2 (Committee, 2013a, 2013b). Based on this definition, the large-scale commercial building demonstrates the characteristics of large building area and scale, large number of people and electric equipment inside, complex evacuation route and high fire load, so it is in a high fire risk. According to statistics of yearly top ten fire accidents in the recent 10 years, commercial building fires accounted for 24%, and large-scale commercial building fires accounted for 2% (Qian-li and Ting-lin, 2011). Specifically, once a fire occurs in the commercial building, it may cause a lot of damage to property and casualties. Large-scale commercial buildings belong to high-risk units. However, until to date, there is no appropriate risk assessment system for large-scale commercial buildings. Therefore, there is an urgent need to establish a fire risk assessment system for large-scale commercial buildings and determine the corresponding building fire risk level. What's more, it has great social and economic significance in reducing the fire risk in large-scale commercial buildings as well as casualties and property loss. Fire risk assessment was originated from the American insurance industry. The Insurance company charged a certain fee by underwriting all kinds of fire damage for the policyholders, and the charge was determined by the magnitude of the fire risk, as a result, the problem of how to measure the level of fire risk was extended. Domestic and international researchers have studied and explored the methods and theories of fire risk assessment, and the main methods contain: standard reference method, logic analysis method, comprehensive evaluation method, and deterministic analysis method.

There are many fire risk evaluation models and corresponding software. Among them, the typical models include: FIERA system (Fire Evaluation and Risk Assessment system) (Benichou, 2005), CESARE-RISK (Centre for Environment Safety and Risk Engineering, RISK) (Beck, 1998), Crisp II (Computation of Risk Indices by Simulation Procedures) (Fraser-Mitchell, 1994), etc.

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Generally speaking, each assessment model has its own characteristics and applicable scope. The model adoption should depend on the specific case during the assessment process, moreover, the precondition and the restriction should be understood adequately. In most cases, the models rely on a large number of input data and particular fire scenario, in addition, the application condition is very strict. According to the target of evaluation, previous researchers have developed some assessment models based on the system theory. For examples: Qian et al. built an urban fire risk assessment index system according to the possibility and the severity of urban fire (Qian, 2012). Ke-xuan et al. built a fire risk assessment index system for large-scale shopping centers according to the fire characteristics (Ke-xuan, 2013). Omidvari et al. who comes from Iran built a fire risk assessment system for education center laboratories based on RPN method (Omidvari et al., 2015). Li et al. built a fire risk assessment system for coal mines, based on TOPSIS method (Li et al., 2011). Jiang et al. built a fire risk assessment system for super high-rise buildings (Jiang et al., 2015). Zheng conducted a fire risk assessment on the Main Stadium of the 12th National Games of China by using the analytic hierarchy process (AHP) method (Zheng, 2014). Sun and Luo, also built a fire risk assessment system for super high-rise buildings (Sun and Luo, 2014). Yang et al. built a fire risk assessment system for underground buildings by using grey relational analysis (Yang et al., 2012).

Most of the mentioned fire risk assessment systems are based on the features of target buildings and equipment of the fire protection system. Nevertheless, fire risk level in the two same buildings with same fire equipment will be different, if the maintenance situation of the fire equipment and the fire safety management capability are different. Besides, the existing large-scale commercial buildings have relatively high fire safety requirements and various of fire equipment, therefore, only relying on the installed fire equipment to evaluate the fire risk is not enough.

There is no special fire risk assessment system for the large-scale commercial buildings, and the application of the existing fire risk assessment system is lack of the consideration of the fire characteristic in the large-scale commercial buildings. Therefore, to establish a fire risk assessment system considering the maintenance situation of the fire equipment for the large-scale commercial buildings will provide significant theoretical and practical values.

A fire risk assessment system for large-scale commercial buildings will be established in this paper, the comprehensive evaluation method was adopted and the detailed scoring system for all fire indexes were included in this system. Firstly, the investigation and research on the management departments, maintenance departments, insurance companies of the large-scale commercial buildings were carried out. Secondly, the indexes in the fire risk assessment system for large-scale commercial buildings was established by using analytic hierarchy process (AHP) method, and the weights of the indexes were obtained by questionnaire and structure entropy weight method. Thirdly, the score of each index was provided by on-site investigation. Finally, the fire risk of the large-scale commercial buildings was evaluated by the total score calculated from the proposed fire risk assessment system.

2. Methodology

The purpose of this research is to establish a fire risk assessment system for large-scale commercial buildings, and take some real large-scale commercial buildings as examples to calculate the total score based on the system. Therefore, the fire risk level depends on the total score. Based on the architectural characteristics of large-scale commercial buildings and considering the maintenance situation of fire equipment and fire safety management, in order to reduce the possibility of a fire and increase the possibility of fire extinction, five main aspects including causing disaster factors, passive fire protection method, active fire protection method, fire protection management, and fire-fighting ability of fire brigade have been covered. This research mainly includes four steps: 1. On-site investigation and risk identification to determine the fire risk assessment index system of large-scale commercial buildings. 2. Use the structure entropy weight method to determine the index weight. 3. Determine the scoring principle, score for the real commercial building and determine the fire risk level. 4. Case study. Four steps were described as follows:

Step 1: Build a targeted fire risk assessment index system for large-scale commercial buildings. First of all, the related fire data, the status quo of fire risk assessment and the fire influence factors of large-scale commercial buildings were achieved through on-site investigation, reading relevant literatures and visiting the insurance company and the third party fire risk assessment institution. Under the comprehensive consideration of reducing the possibility of a fire and increasing the possibility of fire extinction, the assessment index system was preliminarily built thereafter. Some fire experts from design companies, consult organizations, management departments, research institutions and fire brigades who engaged in fire engineering were invited to evaluate the preliminary index system. According to experts' suggestions, this system mainly focused on the maintenance of fire equipment and fire safety management in large-scale commercial buildings. Therefore, considering the reliability of fire safety system in the large-scale commercial buildings, the characteristic of commercial buildings needed a further consideration in assessment system and the index system needed to be refined to every part of the fire-fighting equipment. The establishment of index system was similar to the analytic hierarchy process (AHP); indexes were divided into several layers. Five main aspects, including causing disaster factors, passive fire protection method, active fire protection method, fire protection management, and fire-fighting ability of fire brigade, have been covered. Finally, the fire risk assessment index system used in the large-scale commercial buildings was established.

Step 2: After the index system was determined, the index weight should be assigned to all indexes in each layer. If the traditional AHP method was used to assign the index weights, it would greatly increase experts' workload. Compared with the AHP method, this paper introduced a new method, Structure Entropy Weight Method, to assign the index weight. It combined methods of subjective and objective assignments, as well as the qualitative and quantitative analysis. The detailed principle and application method of the structure entropy weight method will be explained in Section 2.3.

Step 3: To achieve the quantification of the assessment results, it is necessary to assign the scores of the indexes in the bottom layer. For different types of bottom indexes, Grade Security Assessment and the Scoring Method were adopted respectively according to the difference of the indexes. Combined with China's actual situation, the evaluation criteria have been improved. The scoring methods were approved by the experts, and the details will be explained in Section 2.4. Through the previous steps, the index weights in each layer and the bottom indexes scores could be acquired.

In this paper, in order to eliminate the difference between different layers used different methods, the bottom indexes were processed uniformly by Hundred-mark score transferred. The value and level of the fire risk of the large-scale commercial buildings could be calculated and evaluated finally.