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Original

Assessment of Maximum Possible Loss Caused by Fire in High-Rise Buildings Using the LOPA Method: A Case Study on Central Insurance Building of Iran

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ABSTRACT

Background: Fire safety is one of the most important issues in high-rise buildings. The purpose of this study is to assess maximum possible loss in the fire in Central Insurance Building of Islamic Republic of Iran using the layer of protection analysis (LOPA) method. **Method**: In 2017, this analytical study was conducted on the 21-floor building of the Central Insurance in Iran. To identify the hazard sources and assess the maximum possible loss, the authors used the preliminary hazard list (PHL) and layer of protection analysis (LOPA) respectively. In addition, the analysis of the study data was performed based on the 10×10 risk assessment matrix. **Results**: The results of the PHL showed that 26 hazardous conditions and four major sources including structural engineering, fire alarm systems and fire extinguishers, design and maintenance of building safety, and behavioral habits were identified as main hazards of fire in the studied building. The application of the LOPA method showed that highest risk level was associated with the fire caused by the exhaust heat from the engine room (RL=48) and the emergency power generator diesel (RL=40), respectively. **Conclusion**: The findings of this study indicated that calculating the maximum possible loss in the fire of high-rise buildings can help to increase the safety factor. Moreover, the use of the two methods, PHL and LOPA, can be useful in these types of risk assessments.

Keywords: Safety, Fires, Risk Assessment.

Introduction

One of the significant issues affecting health, safety and environment (HSE) is fire. Fire can also threaten the nature of a system because of its damaging and occasionally catastrophic effects. [1-3] Numerous economic, social and cultural losses have been caused by fire in towers and high-rise buildings with administrative, residential and commercial purposes. [4] Recent examples of this type of incident include the Grenfell residential tower fire in London and the Plasco commercial building.

Since high-rise buildings have special fire safety requirements, it is important to consider these requirements. In addition to fire safety problems that exist in conventional buildings, there are three other

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fire safety problems in high-rise buildings: (1) safe egress time from the building, (2) the chimney phenomenon that causes smoke and flames to rise to the upper floors, and (3) access problems for firefighting personnel and equipment. [4]

To date, various studies on the safety performance in high-rise buildings have been evaluated and analyzed in different countries, including Australia, Indonesia, and China. [5-7] According to several studies, hazard identification and fire risk assessment, together with the application of the necessary technical and management measures to control or reduce the probability of accidents and their effects, can significantly reduce the magnitude of losses caused by fire. [8] The amount of loss or the maximum loss caused by fire has not been evaluated yet although some studies have been conducted in Iran on the safety of high-rise buildings. [3, 9, 10] It should be emphasized that this type of assessment can be used as a decision-making tool to increase and improve safety factor in these structures. In recent years, LOPA has proven to be a useful tool for risk assessment. When reviewing a process, LOPA enables decision-makers to determine whether existing safety precautions are sufficient or whether additional layers of protection are needed. Specifically, LOPA seeks to reduce the level of risk to an economically viable and approvable level before determining the remaining risk. [11, 12]

The 21-floor Central Insurance Building of Iran holds a very important place as a symbol of the insurance industry in Iran. The fire risk and its potential damage can be considered a major disaster. This is due to the importance of this building to the insurance business, its location in the spotlight, the likelihood of a fire in this building, in addition to the presence of employees and numerous daily visitors. This study was designed and conducted in order to identify fire risks in this building, classify existing assets based on the severity and loss caused by the fire, identify layers of protection, and assess the maximum conceivable loss.

Method

This research was a descriptive-analytical study designed and conducted with the aim of evaluating the maximum fire damage to the 21-story building of Iran's Central Insurance Company in 2017.

Study location

The 21-story building of the Central Insurance Company has 5 underground floors, which include areas such as the parking lot, the engine room, and the location of the power transformer. The ground floor also includes entrances, elevator, staircase, control room, banks and other departments. In addition, the computer information center and associated offices are located on the first floor. The administrative departments are located on floors 2 to 16. On the 17th floor is the board of governors meeting room, the boardroom and audiovisual control room, the dining room and the restroom are on the 18th floor. On the 19th and 20th floors are the boardroom, offices and the conference room. The 21st floor is also where the air conditioning and other facilities are located.

Preliminary Hazard List (PHL)

PHL is a preliminary method of identifying existing or potential risks associated with system design. It can be used to identify risks through various methods such as checklists, risk matrices, equipment description and explanation, accidents and incidents reports, review of records of similar jobs, and review of other previous reports. [13]

By using a strategy that divides the system into three sections-hardware, labor, and work methods and procedures-and by using tools such as a fire safety checklist, guidance from fire specialists, investigation of past incidents, site visits, and the use of expert witnesses, authors conducted this study within the parameters of the research committee.

Layer of protection analysis (LOPA)

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As a quantitative-qualitative or semi-quantitative risk assessment technique, LOPA seeks to identify and classify as many potential risks as possible in the region under consideration, along with their underlying causes and effects. [12]

The implementation and application of LOPA technique to assess the maximum possible fire damage in Central Insurance building of the Iran was done in such a way that fire-related risk sources were first identified based on the PHL findings. Then, based on this, as well as the existing protection layers and the failure rate in each layer, the occurrence (O) and severity (S) of each of these risk sources were determined in three levels: low (1-3), medium (4-6), and severe (7-10) (Table 1). Finally, using the 10×10 risk assessment criteria matrix, the desired risk level (RL) was divided into 6 levels, including negligible (1-3), very low (4-12), low (13-25), medium (26-42), high (43-67), and very high (68-100; Table 2). The proper control measures were then offered to reduce the risk level based on this established risk acceptance criterion. It should be mentioned that experts' opinions were used to determine the probability to fail demand (PFD) of each protective layer (Table 3).

Table 1. Coordinates of Occurrence and Severity Factors

Grade	Occurrence	Severity (the possible loss amount)
1	Very unlikely (impossible)	Less than 50,000,000 tomans
2	Very, very low (within 10 years)	50,000,000 to 100,000,000 tomans
3	Very low (within 5 years)	100,000,000 to 500,000,000 tomans
4	low (during the year)	500,000,000 to 1,000,000,000 tomans
5	medium (within 6 months)	1,000,000,000 to 2,000,000,000 tomans
6	High (during the season)	2,000,000,000 to 5,000,000,000 tomans
7	Very high (during the month)	5,000,000,000 to 10,000,000,000 Tomans
8	Very, very high (within two weeks)	10,000,000,000 to 20,000,000,000 Tomans
9	Extremely high (during the week)	20,000,000,000 to 30,000,000,000 Tomans
10	Exceedingly high (during the day)	Above 30,000,000,000 Tomans

Table 2. Risk Assessment Matrix

		Occurrence (O)									
		1	2	3	4	5	6	7	8	9	10
Severity (S)	1	1	2	3	4	5	6	7	8	9	10
	2	2	4	6	8	10	12	14	16	18	20
	3	3	6	9	12	15	18	21	24	27	30
	4	4	8	12	16	20	24	28	32	36	40
	5	5	10	15	20	25	30	35	40	45	50
	6	6	12	18	24	30	36	42	48	54	60
	7	7	14	21	28	35	42	49	56	63	70
	8	8	16	24	32	40	48	56	64	72	80
	9	9	18	27	36	45	54	63	72	81	90
	10	10	20	30	40	50	60	70	80	90	100

Table 3. Protection Layers Based on PFD

Probability to fail demand (PFD)	Safety integrity level (SIL)
1×10^{-5} to 1×10^{-4}	4
1×10^{-4} to 1×10^{-3}	3
1×10^{-3} to 1×10^{-2}	2
1×10^{-2} to 1×10^{-1}	1

Results

Based on the results of applying the system description and PHL findings, 26 hazardous conditions in the form of four main sources of risk were identified which can cause fire in high-rise buildings. These sources are: (1) building structural engineering (10 hazardous conditions), (2) fire alarm and extinguishing systems (4 hazardous conditions), (3) design and maintaining the building's safety (3 hazardous conditions), and (4) people's behaviors and behavioral skills (9 hazardous conditions). The results of this section are shown in Table 4.

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Table 4. Hazardous Conditions Causing Fire in High-rise Buildings

classification		Hazardous Conditions
Structural engineering of the building	1	Using non-standard materials in the building
	2	Inadequate building stability due to long service life
	3	Improper and hazardous use of the building
	4	Unsafe electrical panels on the floors
	5	Explosion of obsolete ceiling lights
	6	Short-circuit of electrical wiring inside the false ceiling
	7	Short-circuit in cooling and heating systems
	8	Fire caused by short-circuit of a transformer
	9	Fire caused by an emergency diesel generator
	10	Fire from blower and exhaust fans in balconies and ceiling air conditioners
Fire alarm and extinguishing systems	1	Lack or failure of hand-held extinguishers
	2	Lack or failure of fire detection and warning systems
	3	Lack or failure of intelligent fire extinguishing systems
	4	Lack or failure of fire boxes and firefighting facilities
Design and maintaining building's safety	1	Fire caused by heat from engine room exhaust
	2	Improper design of emergency exit routes and escape stairs
	3	Lack of safe heating systems
	4	Lack of fire doors
	5	Absence of lightning rod and earthing system
	6	Fire caused by the heat of hot water boilers
	7	Improper placement of fuel tanks and failure to comply with standards
	8	Welding and cutting during repairs
	9	Fire in the parking lot and in vehicles (floors 5 to1)
Behaviors and behavioral skills of people	1	Lack of familiarity with safety signs and fire extinguishing equipment
	2	Lack of necessary training regarding not lighting cigarettes and fire
	3	Security failure and the possibility of act of sabotage

Table 5. The Results of Evaluating the Maximum Damage Caused by Fire Using the LOPA Method

hazard	cause	Consequence	occurrence	Severity	RL	Preventive protection layer	occurrence	Limiting protective layer	Severity	RL
Engine room exhaust heat	Exposure to exhaust and proximity to flammable materials	Financial loss to the building and burn	6	8	RL_1= 48	Creating a thermal gap and wrapping thermal insulation of material around the exhaust PFD= 1×10^{-2}	3	Fire boxes and fire extinguishers PFD= 1×10^{-3}	4	RL_2= 12
Diesel emergency power generator	Increasing the load on the engine and generator	Financial loss to the facilities, burn and electrocution	5	8	RL_1= 40	Installing the generator in a proper place PFD= 1×10^{-3}	3	Installation of fire alarm and extinguishing detector PFD= 1×10^{-4}	3	RL_2= 9

Table 6. Average Initial Risk Levels of Each Criterion

Criteria	RL Average
Structural engineering of the building	28.4
Fire alarm and extinguishing systems	25.75
Design and maintaining building safety	26.89
Behaviors and behavioral skills of people	27.67

The results of applying LOPA risk method to evaluate maximum fire damage demonstrated that none of the identified hazardous conditions were assigned to a very high (RL=68-100) or negligible risk level (RL=1-3). In addition, two hazardous

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conditions identified were in high risk level (RL=67-43), including (1) fire caused by engine room exhaust heat (RL= 48) and (2) fire caused by a diesel emergency power generator (RL=40). According to the risk assessment results, 11 hazardous conditions were classified as low risk level (RL=13-25), including (1) building collapse due to fire; (2) fire caused by explosion of obsolete ceiling lights, (3) , short-circuit in cooling and heating systems, (4), and by blower and exhaust fans in balconies and ceiling air conditioners; (5) lack or failure of fire detection and warning systems, (6) intelligent fire extinguishing systems, (7), and fire boxes and firefighting facilities; (8) the spread and transmission of fire to adjacent spaces due to the lack of fire doors; (9) fire caused by lightning, (10) fire in the parking lot and in vehicles (floors -5 to -1); (11) security failure and the possibility of acts of sabotage. Additionally, 11 hazardous conditions were classified as medium risk level (RL=26-42), including (1) inadequate building stability due to long service life, (2) improper and hazardous use of the building, (3) unsafe electrical panels, (4) short-circuit of electrical wiring inside the false ceiling, (5) fire caused by short-circuit of a transformer, (6) fire caused by an emergency diesel generator, (7) lack or failure of hand-held extinguishers and manual extinguishing possibility, (8) improper design of emergency exit routes and escape stairs, (9) ignition of fuel tanks, (10) inability of people to extinguish fire because they are unfamiliar with fire extinguishers, and (11) extinguishing methods for lighting matches and cigarettes. The remaining hazardous conditions, such as fire caused by unsafe heating systems and welding and cutting during repairs, were very low risk (RL= 4-12). Table 5 illustrates the results of calculating maximum fire damage using LOPA risk method for the most hazardous conditions, including fire caused by heat from hot water boilers and fire caused by engine room exhaust heat.

The interpretation of the LOPA method is complicated by the fact that the fire hazardous conditions of the building under study are divided based on four main sources of risk. Each of them has different justifications and the associated failure conditions. In this situation, the average risk level for the four risk sources was also calculated in order to define priorities for the proposed actions and solutions based on their degree of relevance (Table 6). As can be seen, authors predicted that these resources have similar average risks.

Discussion

Results of this study makes it clear that, although fire risk in high-rise buildings can vary depending on their use, the risk level is significant in all buildings. The probability and frequency of fires in such buildings can be low; however, the consequences can be severe and tantamount to a disaster. [14]

26 hazardous conditions indicated that the probability of fire in the studied building is relatively low. Among these 26 hazardous conditions, only two high risk cases were identified. In general, this high-rise building has a good and relatively safe fire safety status. The four selected fire risk criteria have similar risks on average. According to the results of this study, however, the design of the building structure is given priority over the behavior and behavioral skills of people, the design and maintaining of the building's safety, and the installation of fire alarm and extinguishing systems. Consequently, the main control measures for the present and future should focus on technical structures for firefighting, followed by raising awareness and monitoring the activities of those working in the research area. It should be noted that this building can always be considered a priority for special attention to fire safety due to its potential for risk-taking, despite the relatively high degree of safety in the studied environment.

The fire started by the emergency diesel generator, with a primary risk level of 40 caused by the additional load on the generator, the high engine

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temperature, and the ignition of the diesel fuel. It has the highest level of primary risks for this criterion, which is the structural standard of the building. The use of non-standard materials indicated the lowest level of risk for this criterion, with a risk level of 20.

For the second priority, people's behaviors and behavioral skills, the highest level of primary risk in this criterion is the lack of required training with regard to not lighting cigarettes and fire. The primary risk level is 35 caused by people's, employees', and customers' carelessness. The lowest risk level in this criterion was also identified as 18-lack of protection and the possibility of acts of sabotage. In the third criterion, which includes building safety design and maintenance, the highest initial risk level belonged to fire caused by the heat of the engine room exhaust gasses, with a risk level of 48. It was caused by the contact and proximity of the exhaust gasses with combustible materials. The lowest risk level for this criterion was calculated for the absence of unsafe heating systems with a risk level of 8.

The absence or failure of portable fire extinguishers was assigned a risk level of 35, the highest initial risk level in the criteria for fire detection and extinguishing systems (4th priority). The lowest risk level in this criterion was 20 for the absence or failure of warning and notification systems.

According to the results of this study and the results of related studies, fires can occur for a variety of reasons, which is one of the risks that always threaten high-rise buildings. Since fire prediction and prevention are among the most important safety aspects for these type of buildings, fire safety strategies are essential requirements for the construction of high-rise buildings. They should be considered one of the basic design principles for these types of buildings. Because there are many different ways that a fire can start in tall buildings, including the 26 hazardous situations listed above, disregard for safety precautions, accidental fires, and fires that start after an earthquake, tall buildings are vulnerable to fire in this way. [15, 16]

Various detection, alarm and fire extinguishing systems should be designed and used, evacuation of occupants and customers should be ensured in case of fire through proper escape routes, fire risk and generated gases in high-rise buildings should be reduced through limiting protective layers such as fire doors and a suitable communication system with fire stations (8, 14).

A review of various studies did not find a homogeneous study with the objectives and method of this study. A study, however, conducted in Indonesia evaluated the safety needs in high-rise buildings in terms of escape routes (exits), time index, preservation of the lives of residents and building structure, fire detection and extinguishing facilities, the ability of internal and external roads, firefighting and rescue. With the increase in the number of floors in buildings, these needs will be of particular importance (5). Moreover, a study was conducted in Australia to evaluate the reliability of automatic sprinkler systems in 26 high-rise office buildings and to identify the causes of fire risk (6). In China, the safety of high-rise buildings was studied, and one example is the Shanghai Tower's ability to withstand fire by using the right materials in the main columns (7). Besides, studies have been conducted in Iran and other countries on the safety of high-rise buildings, but none of them addressed the issue of maximum damage. Instead, they focused on hazard detection and installation and use of safety devices to reduce the risk of towers fires. The severity of damage when a building collapses due to fire is equal to 10 Therefore, it is important to pay attention to the building's stability and resistance to fire during design and construction. [17]

Conclusion

The results suggest that the central insurance

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building is the most important financial assets that can cause the greatest possible loss in the event of a fire in that building. The people who are in the building are one of the main cases of injury and damage in case of fire or other reasons. As a result, labor force should be considered a very important asset in this high-rise building, both financially and otherwise. The third major asset considered in this study is electrical plant and equipment, such as generators, power transformers, power distribution networks, and ventilation systems, which can cause significant financial losses in the event of a fire. Due to their frequent use and increased risk of fire, furniture and office supplies can be considered the last group of assets that are vulnerable to destruction (8,14).

Conflict of interest

The authors declared no conflict of interest.

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Authors Contribution

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Data gathering: Mohsen Amini

Data analysis and modelling: Ahmad Soltanzadeh; Samira Ghiyasi

Manuscript preparation: Ahmad Soltanzadeh; Hadi Najafiyan; Mohsen Amini

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