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Post-earthquake fires: risk assessment and precautions

Fulya Gökşen, Çağatay Takva *, Yenal Takva, Zeynep Yeşim İlerisoy

Department of Architecture, Faculty of Architecture, Gazi University, Ankara 06530 Turkey

* Corresponding author: Çağatay Takva, Email: cagataytakva@gazi.edu.tr

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ABSTRACT

Earthquakes have great damage potential and importance in risk management and structural engineering, causing fires in buildings such as residences and commercial spaces. Post-earthquake fires (PEF) are secondary disasters that can cause material and moral destruction and loss of life. Similar to natural disasters, they show the time of occurrence and possible scenarios in places. This study aims to analyse and examine what precautions can be taken to prevent or minimize PEF through risk assessment. In this study, a literature review was conducted with the tracking method, focusing on examples from the world where the fires that occur as a secondary effect of the earthquake can cause devastating damages and significant disasters, and inferences are made by classifying the data obtained. Many factors, such as gas leaks due to earthquakes, cracks in pipelines, and short circuits in electrical installations, can cause fires. In addition, flammable liquid or combustible gas emissions and fire protection disturbances create significant fire hazards after earthquakes. In this paper, in which the causes and consequences of fires are analysed, risks, the evaluation process depending on the risks, the precautions that can be taken according to the situations that the risks will cause, and the models developed are emphasized. The research is a reference study with the expectation that there will be an increase in the number of studies examining experimental and physical PEF models.

1. Introduction

In the historical process and recent years, natural disasters have been ongoing around the World [1]. Earthquakes are also among these natural disasters and are in the class of unpredictable and unexpected natural disasters concentrated in certain parts of the World [2]. Earthquakes are natural disasters that bring life to a standstill for people, but secondary disasters that occur after this natural disaster are triggered by earthquakes and are often overlooked [3]. Fires after major earthquakes are one of the dangerous secondary disasters and threatening seismic zones [4], and especially in certain cities with earthquake risk, they cause significant loss of life and property [5]. In some cases, they can have worse consequences to a greater extent than the impact of the earthquake [6]. The frequency and magnitude of fires occurring after earthquakes also vary according to the magnitude and environmental impact of earthquakes. For each different earthquake, the damage of PEF is also different [7]. Although fires occur in many cases, international experience shows that earthquakes are the primary triggers for starting fires [4]. The danger levels of fires are affected by social infrastructure roles, such as water systems, natural gas systems, transportation networks, communication systems, and electrical power systems [8]. Electrical and gas faults are the most common fire triggers; in addition, environments with heat sources are dangerous [9]. Research shows that the spark source for PEF is 15-50% natural gas and 40% electricity [10].

Depending on the location of the fires in the cities, the starting point changes the spreading direction of the fires. In urban areas, the effect of wind also plays a role in the propagation directions of fires. In parallel with the direction of the fires, some factors are also effective in their duration and lead to prolonging the fires. First, most of the urban areas damaged by the fires are associated with the fire epicentre. In areas with wooden structures with low fire performance and narrow streets, the rate of fire spreads quickly between buildings, and multiple structures affect these buildings. In addition, the narrow streets make it difficult to extinguish the fires by hindering the fire response, which increases the loss of life and property [7]. The damages caused by earthquakes and PEF can also vary according to the development level of the countries. Especially in metropolises, the earthquake has both direct and indirect social and economic effects. Earthquakes have great damage potential in terms of causing fires in buildings such as residences and public and commercial spaces, and the earthquake is an essential natural disaster to be considered in structural engineering. Especially for large industrial facilities, planning should be done by considering PEF [11]. While earthquakes make the building vulnerable to structural damage and collapse, non-structural elements (sprinklers, pipelines, etc.) can also be damaged, increasing the duration and intensity of the fires [12].

Major earthquakes and PEF represent risky situations that damage infrastructure and superstructures [6]. An earthquake can cause structural failures and damage to fire protection equipment, making the structure more vulnerable to fires. At the same time, insufficient or low water pressure after the earthquake, multiple independent fires, traffic jams, and limited resources contribute to the growth of fires. The design of buildings vulnerable to fire hazards after earthquakes can become fire resistant by integrating fire safety components in the design of structural systems. In building elements, circulation elements such as facade elements (glasses, curtain wall systems, and other exterior systems), interior partitions, ceiling systems, ventilation, alarm, lighting and electrical power systems, stairs, and elevators should be designed as fire-resistant, both passively and actively [13]. This process is implemented within the framework of performance-based design. As shown in Fig. 1, a performance-based procedure has been proposed for buildings and consists of four steps: hazard analysis, structural/non-structural analysis, damage analysis, and loss analysis [14]. Three types of damage should also be considered: damage to the structure, damage to the fire protection of structural members, and damage to the fire protection of non-structural members. Reassessing fire hazards is also critical as damage to fire protection systems can affect the evolution of fire hazards [4].

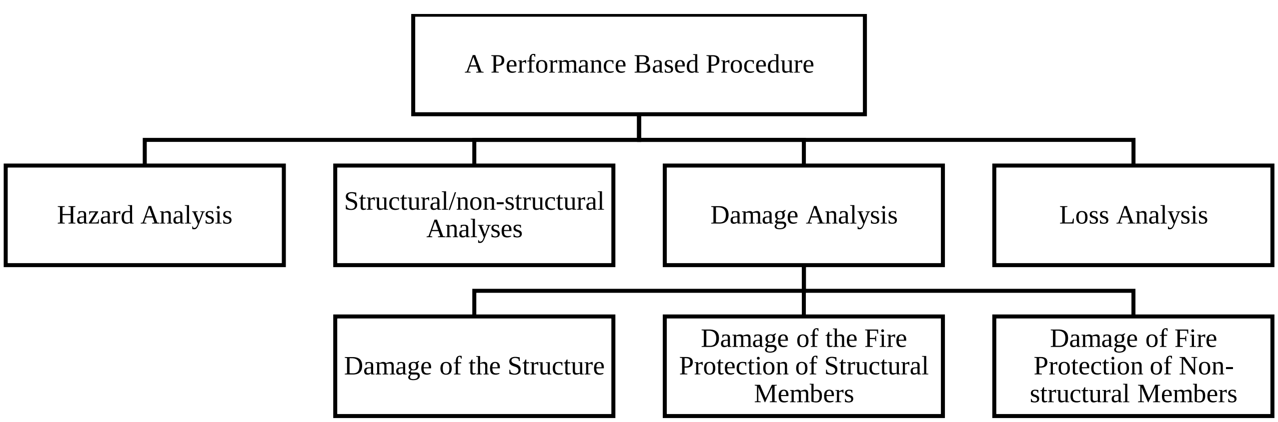

Fig. 1. An action plan developed for buildings that should be done before and after fires [Created by the authors based on [15]]

High-rise buildings are also affected by PEF and are at risk. The presence of a sprinkler system after an earthquake does not guarantee fire protection [16]. In high-rise buildings, limited exit routes, increased escape route length, absence of active fire extinguishing systems, and high wind circulation on high floors are disadvantages [17]. When constructing a high-rise building against PEF, fire simulation applications should be made on all floors of the building, fire evacuation plans should be prepared, smoke curtains should be created to prevent fire and smoke from reaching the upper floors of the building, and evacuation corridors and escape routes should be determined. In addition, building elements that provide fire safety should be used on the facades [18]. In the design of complex construction systems, fire scenarios, the performance of active and passive fire protection systems, fire resistance of building elements, and accessibility of emergency services (water resources, etc.) should be planned [19]. Steps such as determining the building characteristics and the current situation, making quick assessments that can respond to needs urgently, cost calculations and financial situation, performance criteria, government decisions, and impact and loss reviews are followed for remedial decisions in building elements damaged after an earthquake in high-rise buildings [20].

When structures are damaged by an earthquake, protecting them from fire or other non-structural damage caused by water leakage and taking steps to recover quickly should be a critical priority. In this study, attention was drawn to the importance of PEF, which can be as devastating as earthquakes. The study was created from a literature review using the tracking technique and includes PEF analysis, risk assessment process, and precautions to be taken. The literature review covers the fires after the earthquake and the studies on the examples. In the light of the analysis carried out, the date of occurrence of the earthquake, its magnitude, and the number of fires were examined and tabulated. In the evaluation section where the causes and consequences of fires are analysed, the risk assessment process and precautions that can be taken are explained. A basic flow chart of this study is presented in Fig. 2.

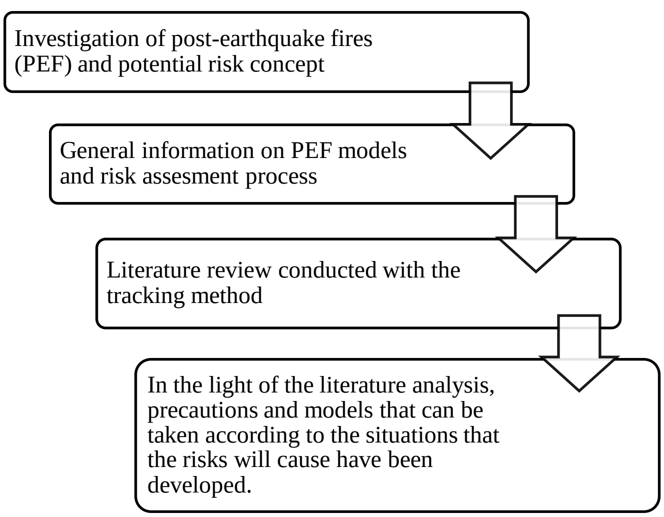

Fig. 2. Flow chart [by the authors]

2. Material and Method

PEF in areas affected by earthquakes is a major problem that often causes more injuries and losses than the effects of earthquakes themselves [21]. In the last century, almost all major earthquakes have caused fires in residential and commercial buildings [22]. Looking at historical records, the 1906 San Francisco earthquake caused multiple fires in city centres where wooden structures were densely dispersed [23]. Of the 521 blocks where the flames spread, 508 were burned. According to statistics, the effect of PEF was four times greater than the direct effect of the earthquake [24]. As a result of the Kanto earthquake in Japan in 1923, over 447,000 houses were burned, and more than 56,000 people died [8]. In 1970, 205 houses were burned as a result of the earthquake in Kütahya Gediz [25]. In 1989, most of the houses were destroyed as a result of PEF in the Marina area of Loma Prieta city in the USA [26]. In the research, 110 fire explosions were reported due to the 1994 Northridge earthquake [27]. More than 7,000 homes were destroyed, and more than 500 people lost their lives in 138 fires that followed the Hanshin earthquake in Japan in 1995 [28]. After the earthquake in Turkey in 1999, oil tanks triggered the fires [29]. The spill of radioactive materials after the earthquake in Japan in 2011 and the oil industries triggered the fires [30]. In the Haiti earthquake on January 12, 2010, the Fukushima earthquake on March 11, 2011, and the Chile earthquake on April 2, 2014, many lives were lost due to PEF [31]. Most recently, the 7.8 and 7.5 magnitude earthquakes that occurred in Kahramanmaraş, Turkey, on February 6, 2023, are also large enough to trigger PEF. The classification of earthquakes according to magnitude and fire ignition characteristics by chronological ordering is given in Table 1.

Table 1

Chronological classification of earthquakes [7, 17, 25, 32]

Event	Year	Magnitude	Fire Ignitions
San Francisco	1906	7.8-8.3	52
Tokyo	1923	7.9	277
Santa Barbara	1926	6.2	1
Napier (Hawkes Bay)	1931	7.75	More than 10
Long Beach	1933	6.3	15
Kern County	1952	7.7	1
San Francisco	1957	5.3	1
Alaska	1964	8.3	7
Niigata	1964	7.5	9
Puget Sound	1965	8.4	1
Santa Rosa	1969	5.7	2
San Fernando	1971	6.6	116
Managua	1972	5.5-6.5	4-5
El Centro	1979	6.4	1
Coalingo	1983	6.7	1
Morgan Hill	1984	6.2	3-4
Mexico City	1985	8.1	200
North Palm Springs	1986	5.9	2
Whitter Narrows	1987	5.9	133
Loma Prieta	1989	7.1	26
Hokkaido° Nansei-Oki	1993	7.8	Multiple
Northridge	1994	6.7	110
Kobe (Hanshin)	1995	6.9	108
Marmara	1999	7.4	Petroleum refinery fire
Napa	2000	5.0	Hotel
Geiyo	2001	6.7	4
Miyagi	2003	7.1	4
Northern Miyagi	2003	6.4	2
Tokachi-oki	2003	8.0	4
Niigata-Chuetsu	2004	6.8	9
Fukuoka	2005	7.0	2
Niigata-Chuetsu-oki	2007	6.8	3
Iwate-Miyagi	2008	7.2	4
Northern Iwate	2008	6.8	2
Suruga-wan	2009	6.5	3
Maule	2010	8.8	A few major
Christchurch	2010 and 2011	7.1 and 6.3	No major fire
Great-East Japan	2011	9.0	293
Tohoku	2011	9.0	330
South Napa	2014	6.0	6
Kumamoto	2016	7.3	15
Northern Ibaraki	2016	6.3	1

Because PEFs have significant negative consequences, they need to be investigated, and risk assessment and precautions should be taken. Within the scope of the study, which focused on risk assessment and precautions, the methods found in the literature were examined. First, after explaining the formation of PEF and how it is triggered, the findings related to risk assessment were given. As a result of the risk assessment process, measures should be taken. At this point, what kind of measures are taken against PEF in the structural sense were tabulated, and then experimental and physical fire models developed on PEF were presented.

3. Post-Earthquake Fires (PEF)

PEF problem consists of complex processes and includes many different elements (Fig. 3). As a result of a PEF, lifelines, fire stations, communication networks, etc., structural and non-structural damage is observed [33]. Earthquake hazards reveal factors such as strong ground movements, liquefaction, fault ruptures, and landslides, and these hazards pave the way for the formation of fires [34]. Shaking directly triggers post-earthquake ignition. A strong shaking causes violent ground movements. This situation brings with it destructions and mobilizes the resources that cause the fires to occur [5].

EARTHQUAKE OCCURRENCE
Structural damage, failure of fire resistant systems (fire walls, sprinkler systems etc.)

↓

Before the firefighters arrive, the fire starts and spreads according to building property, wind condition etc.

↓

Firefighters begin to put out the fire but also deal with chemical leaks and partial structural collapse. Since all fires cannot be intervened, the fire spreads. Firefighting takes time due to the emergence of situations such as water supply, communication etc.

↓

RESULT
The occurrence of small or large destructive fires and casualties

Fig. 3. A simple scenario for PEF [Created by the authors based on [33]]

During an earthquake, roofing systems, fire-resistant walls, sprinkler systems, fire alarms, sensors, i.e. preventive and extinguishing systems can be damaged. The deteriorated roads prevent access to the scene, and the broken water pipes make it difficult to extinguish the fire [35]. Directing the firefighters to different fires by the fire management center prevents them from all going to the same fire area and saves time [36]. It is estimated that the extinguishing rate of general fires is 60% in an earthquake with a magnitude of 5.0, 30% in an earthquake with a magnitude of 6.0, and it will not be possible to extinguish in an earthquake of 7.0 and above. In chemical fires, it is thought that the extinguishing rate will be 50% in earthquakes with a magnitude of 5.0 and 6.0 [37]. The magnitude of the hazard factors varies according to the magnitude of the earthquakes and the magnitude of the damage caused by the earthquakes, and their secondary effects are proportional (Fig. 4). These damages can cause physical and social destruction.

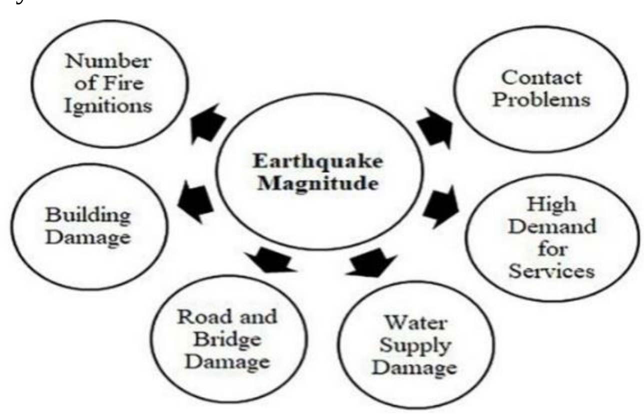

Fig. 4. The magnitude of the earthquake and its secondary effects, which are the hazard factors [Created by the authors based on [32]]

Considering the causes of fires that occurred after the earthquake, especially due to non-structural elements, such as gas, electricity, etc., fires are caused by factors. At the same time, not making a good fire compartment, not applying functional risk analyses in the building, and not protecting the flammable materials in the building can be shown among the causes of fires. Earthquake fires can be classified by looking at the situations that cause the fires (Fig. 5). Fires caused by gases, electrical sparks and tsunamis, and other causes after earthquakes are among the causes of fires. After the earthquake, excessive stresses in the elements in the piping system, slips or overturns in devices such as water heaters, gas leaks, leaks, collection of gas in closed spaces, the amount of gas in the air reaching flammability limits, and the triggering of ignition sources cause gas fires. Electrical fires also occur in electrical distribution connections and sockets, excessive friction of electrical cables and cords with each other, and electrical problems such as overloading and problems with sockets, cables, and extension cords as a result of slipping and rolling of electrical devices and equipment [25]. There are also PEF caused by natural disasters such as tsunamis. The tsunami after the Great East Japan Earthquake of 11 March 2011 caused extensive damage to various oil tanks, industrial complexes, homes, and automobiles in the ports. It also caused gas and gasoline leaks. In this case, fires were triggered as a result of the reaction of flammable gases and metal chemicals with the tsunami [38]. Fires caused by other reasons after the earthquake are situations such as the mixing of chemicals used in places such as chemical laboratories with earthquake shaking, causing explosions with chemical reactions, etc.

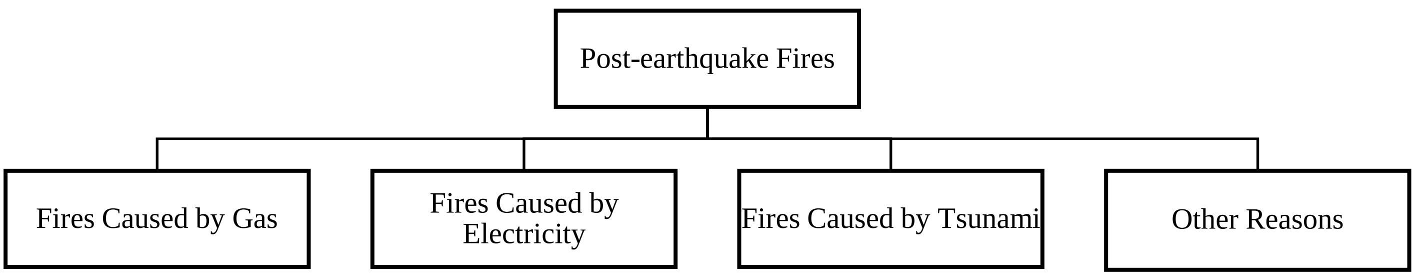

Fig. 5. Main reasons triggering PEF [Created by the authors]

4. Risk Assessments of PEF

PEF are especially risky for building elements (such as wood) and structures that are prone to fire and ignition in seismic regions. There are many opportunities and examples to reduce this risk. Risk management decisions should be developed, such as considering alternative water sources to reduce vulnerability at fire stations and improve firefighting in emergencies. Other facilities such as fire stations and hospitals in seismically hazardous areas should be evaluated according to modern methods as they will be basic structures for immediate functional use after earthquakes. In many cities, fire stations are up to 100 years old, and many were built before 1980. The vulnerability of fire stations to seismic effects directly damages the health and safety of firefighters and indirectly damages fire trucks [39]. In PEF, the location of the explosion, population distribution, weather [40], high earthquake intensity, high wind speed, wind direction, and wooden constructions are the factors that increase the damage size. Looking at the data, large fires occur when high-intensity tremors, accompanied by high winds and dominated by wooden structures, occur in an urban area and threaten residential areas by triggering urban fire occurrences. A risk assessment matrix depending on the earthquakes that occurred is given in Table 2 [32].

Table 2

Risk assessment matrix obtained depending on the speed of the wind and the magnitude of the earthquake [Created by the authors based on [32]].

Fire Risk by Wind and Earthquake		Earthquake Magnitude			
		4-5	5-6	6-7	7-8
Wind Speed	0-20	LOW	LOW	MODERATE	HIGH
	20-80	LOW	MODERATE	HIGH	EXTREME

In general, risks are used to evaluate an event at various losses due to factors that have uncertainty [40]. At this point, fire departments, emergency planners, and the insurance industry have developed risk models to predict and plan the potential frequencies and damage levels of PEF. These models aim to make assessments and regional improvements to provide earthquake loss estimates and possible PEF risk reduction [41]. Methodologies have been developed in line with the determined objectives. Determining the damage situation according to the seismic performance level by looking at the intensity of seismic events, determining the remnants of the structures exposed to fire based on their seismic damage capacity, and conducting studies are some of these methodologies [42]. One of the factors affecting fires after an earthquake is ignition sources. It is important to determine the sources that can create sparks, cause fire, and make a risk analysis accordingly. In Fig. 6, the concept relationship model of the ignition sources related to structural damage and usage is given [43]. Optimal solutions should be found in terms of ensuring risk management after PEF. Divider walls, smoke curtains, and sprinkler systems should be built to control the ignition elements, the flammability of the materials in the building, and escape routes, and legal requirements for appropriate escape routes should detect the fire as soon as possible with the developed systems to prevent the spread of fire in the buildings and control it [44].

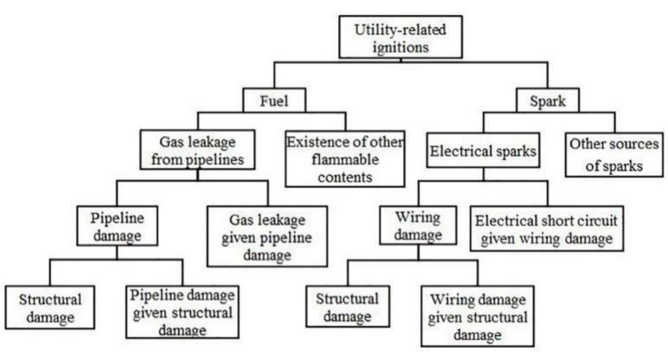

Fig. 6. The connection of the ignitions associated with the use and the association of this use with the main components [43]

The first step in analysing PEF is to determine the parameters for solving the problem and observe the effects of these parameters. A full probability methodology for PEF analysis was developed in the late 1970s [45]. It has been applied in western North America, and in major cities such as Tokyo and Istanbul. This methodology consists of sub-titles of occurrence of the earthquake, ignition, discovery, report, response, and suppression [39]. Due to the high loss of life and property, it has become necessary to establish an appropriate risk management mechanism [46]. This mechanism also includes fire protection strategies. Fire protection strategies aim to protect structures and equipment from radiation, convection, heat transfer, and direct flame strikes, both actively and passively. Rising temperatures pose a danger in many cases. For example, it weakens the structural identity of the steel and causes the steel to break after a certain degree. Increasing temperatures in oil and pipelines cause explosions by entering into reactions. In addition, steam explosions occur with the effect of increasing temperatures [11]. During the risk management process, the possible effects of the earthquake and the extent of triggering the fires should be considered. As seen in Fig. 7, in the fire process that occurred after the earthquake, after the fires were triggered as a result of the damage caused by the earthquake when the detection stage passed, the fire brigade informs the emergency teams of the fire, and after the firefighters arrive at the fire site, they intervene (if there is no malfunction in the water resources due to the earthquake).

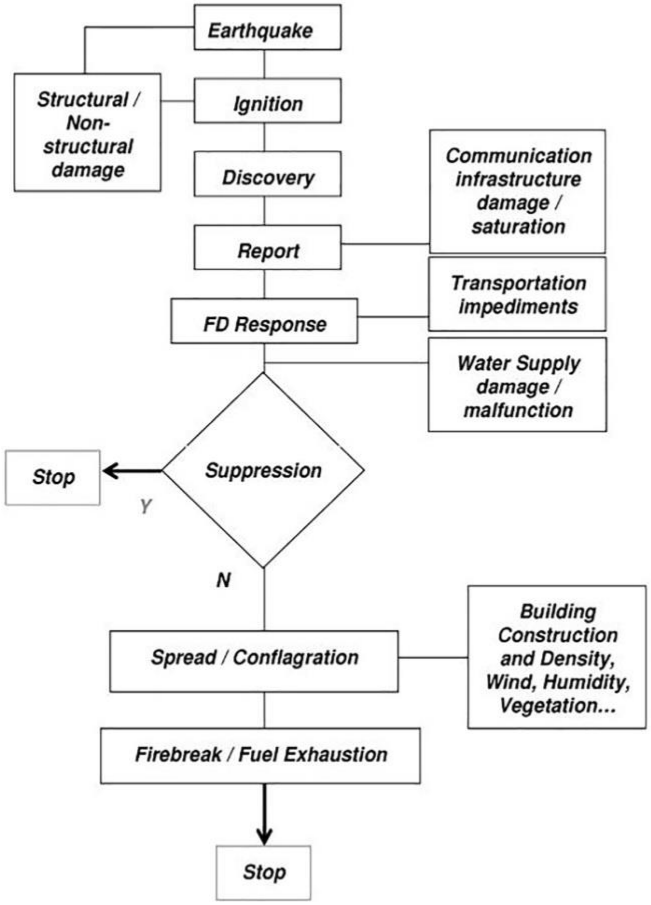

Fig. 7. PEF risk assessment process [8]

5. Precautions to be taken for PEF and Developed Fire Ignition Models

Damage to structural and non-structural parts in PEF poses a great risk [47]. Studies in which the fire resistance of structural systems are determined and experimental analyses are made are given in Table 3 by scanning the literature. According to the data in Table 3, it has been observed that fire resistance tests are high on the basis of structural elements (columns and beams). In general, there are studies on reinforced-concrete and steel frame. In addition, studies on composite materials are also increasing. It is anticipated that fire tests with nanotechnological materials will increase in future studies.

Increasing the resistance of the structural systems against fire and at the same time exhibiting the behaviour of the structure with the least damage in PEF have an important place among the precautions. In addition, damage to the sprinkler system significantly weakens the fire extinguishing. Especially in some structures (hospitals, schools, nursing homes, etc.) people are injured or trapped [48]. In these situations, firefighters must enter unfamiliar environments. To create a good evacuation corridor, it is one of the precautions that should be taken by firefighters to practice beforehand and accordingly be familiar with such situations. It is important to apply fire rescue scenarios after earthquakes and provide realistic and reliable training [47]. While fire drills can be performed with real fire [49], virtual reality technologies are also used in these drills recently [47]. Apart from the exercises, active and passive fire protection systems are also important in preventing fires. Active fire protection systems consist of detectors, alarms, and fire sprinkler systems, while passive fire protection systems include items, such as fire-resistant partition systems, fire doors, fire stop systems, fire-resistant coatings on structural elements, etc. [50].

Table 3

Examining the studies measuring the fire resistance of structural systems in the literature [Created by the authors]

References	Explanation
Song et al. [51]	A nonlinear analysis of steel-frame structures by considering explosion and secondary fire
Della Corte et al. [52]	The first comprehensive studies on PEF response of unprotected moment-resisting steel frames
Li and Wang [53]	The fire resistance of steel structural members by means of experimental and numerical research
Bhargava et al. [54]	The fire resistance of an earthquake-damaged reinforced-concrete (RC) frame
Liu et al. [55]	A fire test on RC beams with a carbon fiber cloth
Pucinotti et al. [56]	The mechanical properties of beam and column joints of steel–concrete composite structures under PEF
Ervine et al. [57]	A test eight RC beams with cracks
Miao and Chen [58]	Three full-scale fire tests on a single-layer frame structure using the crack
Behnam and Ronagh [59]	A fire analysis two RC frames subjected to a spectral peak
Jiang et al. [60]	2D frame analyses to observe various collapse mechanisms: heated bay collapse, column buckling, local lateral drift of heated floor, and global lateral collapse
Fischer [61]	Full-story fires and varying the fire-resistance ratings on the structural members
Kamath et al. [62]	Full-scale fire tests of RC frame structures
Wen et al. [63]	The fire resistance of RC columns that exhibited earthquake damage
Pantousa and Mistakidis [64]	A study on 3-dimensional steel frame performance subjected to PEF
Wu et al. [65]	The fire-resistance limit and influencing factors of cross-shaped RC columns
Wen et al. [66]	The fire behaviour of earthquake damaged beam members

Table 4

General information on PEF models [Created by the authors]

Model Name	Year	Model Type	References
Hamada	1951, 1975	Empirical	Lee [69]
Horiuchi	1974	Empirical	Lee [69]
Scawthorn et al.	1981	Empirical	Lee [69]
Murosaki	Not available	Empirical	Lee [69]
AIRAC	1987	Empirical	Scawthorn et al. [8]
Omori et al.	1990	Empirical	Lee [69]
NDC	1992	Empirical	Scawthorn et al. [8]
SERA	1995-2003	Empirical	Scawthorn et al. [8]
TOSHO	1997, 2001	Empirical	Lee [69]
HAZUS	1997	Empirical	Scawthorn et al. [8]
ICLR	2001	Empirical	Scawthorn et al. [8]
Himoto/Tanaka	2000-2006	Physical	Lee [69]
Morandini et al.	2001	Physical	Morandini et al. [70]
Lopes et al.	2002	Semi-empirical	Lopes et al. [71]
URAMP	2002	Empirical	Scawthorn et al. [8]
Cousins et al.	2002-2006	Empirical (Static)	Lee [69]
Cousins et al.	2002-2006	Physical (Dynamic)	Lee [69]
Otake	2003-2004	Physical	Lee [69]
Bertinshaw and Guesgen	2004	Physical	Bertinshaw and Guesgen [72]
Iwami et al.	2004	Physical	Lee [69]
Ohgai et al.	2004	Empirical	Lee [69]
Ren and Xie	2004	Physical	Lee [69]
ResQ Fire Sim	2004	Physical	Lee [69]
Hansen	2005	Empirical	Hansen [73]
Himoto and Tanaka	2008	Physical	Himoto and Tanaka [74]
Lee	2009	Physical	Lee [69]
Cheng and Hadjisophocleous	2009	Physical	Cheng and Hadjisophocleous [75]
Tabucchi et al.	2010	Empirical	Tabucchi et al. [76]
Zhao	2010	Physical	Zhao [5]
Himoto and Tanaka	2012	Physical	Himoto and Tanaka [74]
Nishino et al.	2012	Physical	Nishino et al. [40]
Li and Davidson	2013	Physical	Li and Davidson [77]
Nishikawa et al.	2014	Physical	Nishikawa et al. [78]
Wu et al.	2014	Physical	Wu et al. [79]
Cheng et al.	2015	Empirical	Cheng et al. [80]
Khorasani et al.	2017	Physical	Khorasani et al. [81]
Lu et al.	2020	Empirical	Lu et al. [47]

Post-earthquake ignition is directly related to the built environment and how buildings respond to strong ground motions. Predicting ignitions and taking precautions accordingly gains importance in this direction. Many PEF ignition models are based on the statistical correlation between strong ground motion parameters and average fire frequency observed in past earthquakes [34]. PEF models provide an estimation of fire risk in terms of fire spread rate and the geographical extent, and an understanding of how fire spreads. Emergency managers, insurance companies, building owners, utilities, and other risk managers can use this information for loss estimation and apply it in the development of risk reduction strategies [67]. The classification of ignition models is shown in Table 4. PEF models are divided into physical and empirical. While physical models represent tests performed in a specific real environment, empirical models include virtual environments and simulations. According to the data in Table 4, the majority of studies on PEF models were conducted before 2020. At this point, studies should be increased to develop an effective system with PEF models. In addition, as we move from the first models to today's models, there has been a shift from empirical tests to physical tests. It is anticipated that more efficient models can be created with the combination of physical and empirical tests.

PEF mitigation precautions are addressed at the regional or site level and the individual building level. At the field level, the geographical information system (GIS) demonstrates an effective analysis process. This system provides geographic distribution information on services such as human injuries, ignited fires, emergency locations, fire stations, hospitals, and the transportation system [19]. At the regional level, it covers PEF ignitions due to short circuits, fire ignition due to failure of gas distribution systems, fire spread between structures, disruption of water distribution networks, development of water-based fire protection systems, and design of lifeline systems for earthquake and PEF [68]. At the individual building level, systems are developed according to the characteristics of each building [19].

Taking the relevant precautions and detection for PEF significantly reduces losses and other negative effects. Strategies, plans and individual measures that can be prepared in this context have a very important place [82-88].

4. Conclusion

PEF are possible major disasters and can cause significant losses and structural damage. Aftershocks, sparks resulting from a short circuit of electricity, damage to transformer centres, the collapse of infrastructure systems, and ignitions as a result of contact with water are the harbingers of PEF. Factors such as the old installations in buildings, the density of buildings and people, and the presence of flammable substances in the environment increase the risk of fire. As a result of these factors, the probability of fire risk increases with the occurrence of earthquakes. To reduce the risk of fire in these areas where there is an earthquake risk, building installation systems should be renewed, narrow streets should be emptied for the response teams to work comfortably, and compartments should be built in areas where there are dense and flammable materials for buildings to prevent PEF. Most of the fires in damaged buildings after the earthquake are caused by damages such as breaks and ruptures in non-structural elements. These elements cause damage and explosions, especially in natural gas pipes, and are an important factor in the occurrence of fire. Explosions occur when gases emitted from natural gas pipes after an earthquake encounter sparks or any burning substance. Although the valve flows are closed during an earthquake, the gases remaining inside can cause large explosions. For this, it is necessary to install systems that allow the gas remaining in the pipe to be evacuated in case of an earthquake and cut the gas directly when sparks are triggered. To prevent explosions and reduce the effect size of possible fires, it is necessary to make a risk assessment, prepare simulation tests, and take precautions. To reduce the risks at the building scale, it is important to make improvements in the structural system, make the building elements resistant to fire, and plan the facade-bearing system design by considering the fire reality.With the development of post-earthquake ignition models, one of the main objectives should be to preparefor these disasters by making experimental and physical evaluations.

In order to prevent fire-triggering situations caused by earthquakes, systems that detect vibrations in advance, especially in earthquake regions, should be expanded. The use of a pre-earthquake warning and safety system is important in protecting structures and living standards. Thanks to these systems, effective solutions can be developed by gaining evacuation time without earthquakes. Appropriate fire extinguishers, smoke detectors, and sprinkler systems should be used in the buildings according to the characteristics and size of the residence or workplace, functional risk analyses for fire should be created, and periodic maintenance of the buildings should be done. Concerning PEF, the aim of this article is not only to ensure human safety but also to maintain rapid recovery by considering minimum structural damage. At this point, it is aimed to raise awareness at the social level by taking remedial and developing technological precautions.

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6. References

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