11 WCEE

Paper No. 110. (quote when citing this article)
Eleventh World Conference on Earthquake Engineering
ISBN: 0 08 042822 3

AN INVESTIGATION OF POST-EARTHQUAKE FIRE HAZARD IN URBAN AREAS

JAMSHID MOHAMMADI,[1] and PATRICK GROBBEL[2]

1 Civil and Architectural Eng., Illinois Institute of Technology, Chicago, IL USA
2 Travelers Insurance Group, Vienna, Virginia USA

ABSTRACT

The potential risk associated with post-earthquake fires in: (i) residential single family homes; and (ii) residential community housing such as mobil homes is presented. Fire statistics for most recent earthquakes are investigated and reported in terms of their causes and severity. As described in the paper, the results of a simple risk analysis can be used for property loss estimation and insurance premium purposes. Post-earthquake fires can be the results of such factors as: (i) gas leaks due to failure of pipes or gas appliances; (ii) electrical distribution system problems; (iii) flammable materials spills; and (iv) overturning of burning candles, table lamps, gas grills etc. A systematic formulation of the risk for all types of fire is nearly impossible. Analytical models have been used with some success to estimate the risk of appliance failure, i.e. sliding or overturning, and interior gas piping system failure during an earthquake. In cases where analytical modeling cannot be developed, techniques based on the extrapolation of fire statistics for non-earthquake conditions are suggested in this paper.

KEYWORDS

Earthquake Fires, Fire Risk Mitigation, Risk Analysis, Urban Planning

POST-EARTHQUAKE FIRES, AN OVERVIEW

Post-earthquake fires have been considered among major devastating hazards in many recent earthquakes. Dramatic scenes from earthquakes in San Francisco, 1989; Northridge/Los Angeles, 1994; and Kobe, Japan in 1995 have attested to the severity and seriousness of the risk of fire following earthquakes. In fact, statistics show that fire can become a major earthquake hazard just about in any earthquake that can occur in an urban area. The fires after the 1906 San Francisco, California earthquake caused damage to a major portion of the city and lasted for three days. Fires were also reported following several other California earthquakes such as in 1933 in Long Beach, 1971 San Fernando and 1987 Whittier-Narrows earthquakes. The fire caused by the 1989 Loma Prieta earthquake in San Francisco's Marina district and fires during and after the Northridge/Los Angeles earthquake of 1994 are examples of the damage potentials of a post-earthquake fire to a populated area. In the Northridge earthquake, aside from many isolated fires, the flash-over fires in mobile home parks brought about new concerns over this potential hazard. Table 1 presents the number of fires following several important earthquakes in the United States. Fires have also been reported in Japanese earthquakes. The 1923 Tokyo earthquake resulted in fires over 40 percent of the city. In the Hokkaido-nansei-oki earthquake in 1993, a fire at the Aonae community on the southern tip of the Okushiri island destroyed 340 homes (about half of the homes in the community). The 1995 Kobe earthquake resulted in hundreds of fire, some of which were due to ruptured gas lines. These events indicate the importance of post-earthquake fires in terms of their potential to cause structural damage and demonstrate the need for post-earthquake fire hazard mitigation planing.

Post-earthquake fire hazard has been recognized as an important element of seismic safety evaluation of buildings. Thus a method that can effectively be used to determine the risk associated with fires following a probable earthquake will be helpful in the evaluation of safety of buildings at the design stage and after occupancy. For mitigation purposes, one needs to identify the risk associated with an earthquake-related fire in, for example, a typical residential dwelling or in row houses, in mobil homes and similar housing that may be subject to flash-over conditions. Furthermore, an investigation of potential causes and effect of post-earthquake fires can be helpful in planning and design to mitigate the risk. Post-earthquake fire hazard often persists for several days after the occurrence of the earthquake. For example, an earthquake may result in a gas system failure and gas accumulation which may initiate a fire in a later day. In regard to fire spread in urban areas, methods for simulation of fire outbreaks following earthquakes have been developed in both US and Japan. Relations for fire growth in urban areas considering wind speed and direction as well as building density, materials, and time of occurrence have been taken into consideration. These models, however, do not consider the risk of fire following an earthquake for a residential unit due to factors that are specific to interior utility systems and appliances.

Table 1. Fires Following Earthquakes in U.S.

Event/Date	Number of Fires	Intensity (MMI)	Magnitude (Richters)
San Francisco/1906	58	VIII1/2-IX	8.3
Santa Barbara/1926	1	VIII1/2	6.2
Long Beach/1933	13	IX	5.3
San Francisco/1957	1	VI1/2	5.3
Alaska/1964	7	X	8.4
Puget Sound/1965	1	VII1/2	8.4
San Fernando/1971	109	VII-IX	6.7
Coalingo/1983	1	VIII	6.7
Morgan Hill/1984	6	V1/2-VII	6.2
Whittier-Narrows/1987	6	VIII	5.9
Loma Prieta/1989	67	VI-VII	6.9
Northridge/1994	87	VI-IX	6.8

A variety of reasons may cause post-earthquake fires. Some reported factors are: (i) gas leaks due to failure of pipes or gas appliances; (ii) electrical distribution system problems; (iii) flammable materials spills; and (iv) overturning of burning candles, table lamps, gas grills etc. Gas and electrical distribution systems and appliances (i.e. water heaters) are used continuously and as such are more exposed to the risk than are elements such as burning candles and lamps. A systematic formulation of the risk for all types of fire (in terms of all potential causes) is not easily possible. Analytical models have been used with some success to estimate the risk of appliance failure, i.e. sliding or overturning, and interior gas piping system failure during an earthquake. Such models can be extended further for the purpose of estimating the risk of fire that may occur due to the appliance failure (URS, 1988). In cases where analytical modeling cannot be developed, techniques based on the expert opinion data and/or the extrapolation of fire statistics for non-earthquake conditions can be utilized (Mohammadi, et al, 1992). It is also important to gather data on the cause and effects of post-earthquake fires in past events and utilize such data in identifying specific measures that can be taken to mitigate the risk in a single family residential unit or in a housing community such as a mobile home park.

POST-EARTHQUAKE FIRES IN RECENT EARTHQUAKES

The January 17, 1994 Northridge Earthquake

The data on Northridge earthquake fires are from various sources (including Scawthorn and Khater, 1994 and Todd, et al., 1994) compiled by the authors. The earthquake affected one of the most densely populated areas in the United States. The fire protection service to the area is primarily provided by the Los Angeles City Fire Department (LACFD), supported by local departments from the municipalities of San Fernando, Burbank, Pasadena and Glendale. The Los Angeles County Fire Department provides protection in sections of the central Los Angeles Basin, as well as outlying areas of the county. Ventura County fire protection is provided by a number of local departments. Fire protection comprises of public (municipal fire departments), private (automatic sprinkler systems), and/or combination of each. Following a major earthquake, the compatibility of both is usually disrupted. The interaction between these systems in reducing the loss from fire is complex because it relies on numerous decisions on part of a great number of people representing local, city and federal agencies. Although emergency operational plans exist, failures of these systems create a great atmosphere for prompt, rational decisions in order to accomplish the single goal of the reduction of the loss of fire and property caused by fires resulting from the earthquake.

The data gathered following the Northridge incident indicates that a significant number of initial fires were caused by natural gas leaks. Natural gas is the primary fuel used for space and water heating in the Los Angeles area. Electricity is also used but the majority of buildings are serviced from natural gas. Natural gas is not in itself an ignition source, but it is easily ignited in confined spaces. Although electrical power was lost in the area after the earthquake, the most common ignition source created was a combination of electrical sources, i.e. fuses/breakers and flames in the gas appliances. Gas leaks occurred in underground supplies (mains) and private lines (pipe links from mains connections) both inside and outside of buildings. Fires were known to have been caused by ruptures in gas mains under streets, which destroyed numerous homes. Water heaters, inadequately secured, tripped over in a number of multi-unit buildings, also creating a source of natural gas leaks.

In the San Fernando Valley, hundreds of mobile homes shook off of their pedestal foundations. Detachment of structures from the foundations had dramatic effects on utility lines especially gas and propane. Approximately 150 mobile homes were destroyed by multiple fires at three separate parks. The exact number of fires is unknown due to the overwhelming individual fires and lack of communication between firemen and dispatchers. These fires were the result of both natural gas leaks and propane fuel ruptures. Luckily, on the day of the earthquake, the treacherous Santa Ana winds, which could easily have caused numerous conflagrations, resulting in even greater potential losses, were relatively calm. These types of causes were reported throughout the affected area. The natural gas leaks were a significant contributor as fuel for the fires.

The secondary or post ground shaking fires were caused by the restoration of electricity. Numerous electrical shorts occurred when the electric company line service technicians attempted to repair downward power lines during the late evening of 17 January 1994 and continued over the next few days. Additionally, some fires were due to damage to electrical equipment that was unknown or unattended to in several buildings. The exact number of electrical fires is unknown.

There were no reported fires due to chemical spills or flammable liquids. Since the fires occurred while a great percentage of the area population was asleep, fires resulting from overturned candles, grills or industrial processes were not reported. However, there were a small number of wildland grass fires caused by arcing in overhead electrical power lines.

The October 17, 1989 Loma Prieta Earthquake

The earthquake occurred on October 17, 1989 with a magnitude of 6.9-7.1 Richters. The earthquake source was along a section of the San Andreas fault where major earthquakes have also occurred in the past. The earthquake caused damage in San Francisco, San Jose, Santa Cruz and areas in Northern California.

The fire data obtained through local fire departments revealed a total of 41 fires in San Francisco. Of these, 17 occurred on October 17, immediately after the earthquake, 13 on the next day (October 18), 8 on October 19, and 3 on October 20, 1989. The causes of major fires were reported to be due to gas and electrical system failure. Isolated causes such as overturning of lamps were also reported.

Further investigation of the San Francisco fires was made (Mohammadi, et al, 1992) in an attempt to correlate the number of fires in terms of their severity, the earthquake intensity, and the type of soil and population density at the sites where the fires occurred. The number of fires seems to be somewhat independent of the intensity. However, as expected, more number of fires occurred in densely populated areas. An examination of the soil types reveals that the affected areas are mainly made of four major types. These are: (i) stable bedrock, (ii) unstable bedrock, (iii) unconsolidated soil, and (iv) mud and fill. The earthquake shock transmitted to the areas with unconsolidated soil and mud and fill is expected to be strongly increased; whereas, the shock in stable bedrock is not increased and in unstable bedrock is only slightly increased. Accordingly, because of the greater potential for building damage in areas with unconsolidated soil or mud and fill, more number of fires are expected in these areas. An investigation of the 41 fires indicated that most fires (33 out of 41) occurred at sites on unconsolidated soil, 5 at sites on mud and fill and the rest at sites on stable rock. It is emphasized that the population density also plays an important role in the number of fires. Regarding the large number of fires reported at sites on unconsolidated soil, the vastness of coverage of this soil type versus the other types may also be a factor. Areas along the San Francisco Bay are mainly on mud and fill soil. However only a few fires were reported in theses areas mainly because of their less population densities.

Aside from San Francisco, fires were also reported in Berkeley, Santa Cruz, Santa Clara and Westonville. Berkeley had a major fire in an auto-service building. The fire started from the ignition of spilled solvents and required the response of the entire fire department. Santa Cruz County had a total of 20 fires. The City of Santa Cruz had only one residential structure destroyed by fire. In Westonville, one single-family dwelling and two mobile homes were destroyed due to fire. In Santa Clara County, a residential fire was reported. This fire started due to a ruptured propane tank.

Recent Japanese Earthquakes

Fires have been reported in almost all Japanese earthquakes that occurred in populated areas. The two major recent earthquakes in Japan were the 1993 Hokkaido-nansei-oki earthquake; and the 1995 Kobe earthquake. In both these events many fires occurred. During and after the Hokkaido-nansei-oki earthquake in 1993 (EERI, 1993), a fire at the Aonae community on the southern tip of the Okushiri island destroyed 340 homes (about half of the homes in the community). The 1995 Kobe earthquake resulted in hundreds of fire, some of which were due to ruptured gas lines. In most these events fire fighting activities were hampered by inadequate supply of water and narrow streets crowded by traffic or closed due to damage to many buildings and bridges in the city. About 100 fires broke out within minutes after the earthquake in Kobe in areas with low-rise mixed residential/commercial buildings. The total number of fires for January 17, 1995 was 142. In addition to these, the city of Ashiya experienced eleven fires on January 17 (Comartin, et al, 1995).

EFFECT OF REGIONAL SEISMICITY AND DEMOGRAPHICS

The number of fires is expected to be directly correlated with the intensity of the earthquake. However, post-fire statistics reveal that generally-speaking there is no simple direct relation between the number of fires and regional intensity values for a given earthquake. This is mainly because:

- Post-earthquake fires do not follow a systematic cause and are due to a variety of factors.
- Densely-populated areas experience more fires.
- A favorable condition of wind (velocity and direction) and housing arrangement in a subdivision can increase the possibility for flash-over fire even though the seismic intensity may not necessarily be high.
- Risk of fire following an earthquake exists several days following the main earthquake event.

Among various causes of post-earthquake fires, those that are related to gas and electric system failure are more predictable and can be mathematically modeled with certain approximations and assumptions. For these causes, a direct correlation between the number of fires and the earthquake intensity can be expected. Formulations presented in URS (1988) and Mohammadi, et al., (1992) use a event tree method to relate an incident of gas system or electric system failure to a given level of earthquake intensity. The underlying assumption in the modeling presented in Mohammadi, et al. is that a higher intensity will increase the probability of a gas appliance (e.g. water heater) overturning or gas pipe rupture. These events in turn will dramatically increase the risk of fire. Figures 1 and 2 present the logical steps leading to an incidence of fire following an earthquake. The starting event is the ground shaking acceleration experienced by the site where a gas or electrical system is located. Conditional probability formulations can then be used to correlate the probability of fire to the probability of the occurrence of a given intensity. For example for gas related fires (see Fig. 1), one can write:

$$P(C_i)=P(C_i|E)[P(E|D)P(D|B)+P(E|F)P(F|\bar{D})P(\bar{D}|B)]\ P(B|A)P(A) \qquad (1)$$

In which $P(C_i)$ is the probability of a consequence (i.e. fire) with index i ($i=1,2,\ldots$) indicating, for example, the type of fire in terms of its severity. It is noted that events B, $\bar{E}$ and $\bar{F}$ do not participate in the sequence of fire development. It is also noted that in the above equation, the fact that there are two possible branches leading to a fire has been included. The estimation of $P(C_i)$ requires that all probabilities involved in the equation be quantified. Mathematical modeling can be employed to quantify some of these probabilities. For example, an appliance failure probability can be estimated by modeling the motion of the appliance subjected to a known earthquake record and investigating the possibilities for overturning or sliding (Mohammadi, et al, 1992).

For an electric system, the probability $P(C_i)$ of a fire can be obtain through Eqs. 2 (see Fig. 2).

$$P(C_i)=P(C_i|E)P(E)+P(C_i|\bar{E})P(\bar{E}) \qquad \text{(2-a)}$$

$$P(E)=\Sigma_{j=1\text{-}3}P(E|D_j)P(D_j) \qquad \text{(2-b)}$$

$$P(D_j)=P(D_j|B)P(B|A)P(A) \quad j=1,2,3 \qquad \text{and} \qquad P(\bar{E})=1-P(E) \qquad \text{(2-c)}$$

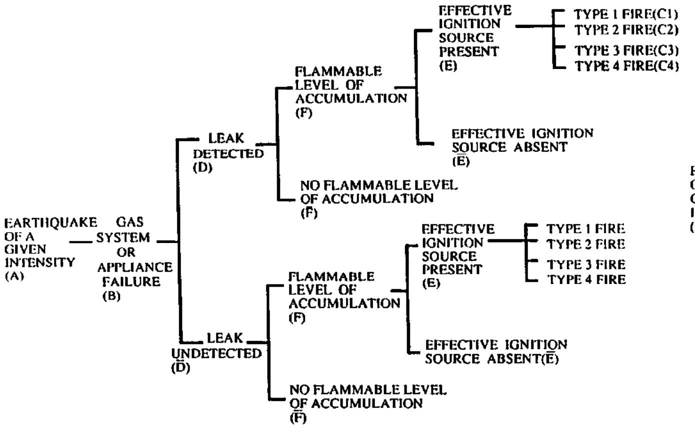

Fig. 1 Sequence of Events in a Gas-related fire

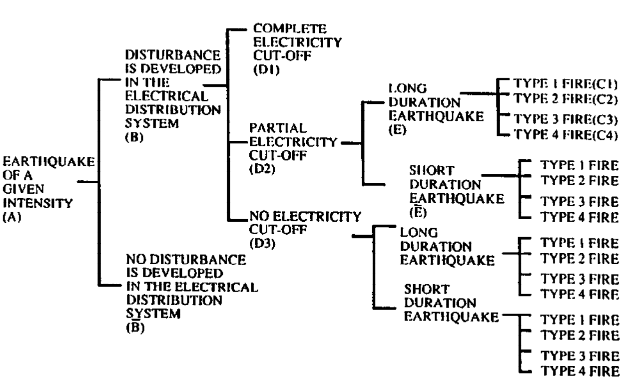

Fig. 2 Sequence of Events in an Electric-related Fire

Generally-speaking, a diverse group of factors such as demographics, population density, concentration of housing units, types of housing, concentration of commercial establishments, and percentage of houses using safety devices (straps to attach water heaters to the wall, sprinklers, automatic gas shut-off valves) affect the number of post-earthquake fires. Unfortunately, development of a systematic approach to correlate these factors to the number of fires is nearly impossible. Past data can be used as a basis to describe the significance of these factors on the number of fires. However, it is noted that due to the variety of such factors, each earthquake represents a rather unique combination of certain number of these factors that were effective in the number of fires developed. Nevertheless, by knowing that these factors can be significant in causing fires, one can develop a plan to reduce the risk to certain extent by controlling one or more of such factors.

QUANTIFYING THE RISK

As briefly described in the previous section, mathematical modeling can be used, to certain extent, to estimate the probability of a post-earthquake fire. Two quantify the risk, one must consider the following two major analyses:

- Risk quantification for a given unit independent of its location in the seismic area and independent of its relation with respect to other units. We call this type of risk the "residential unit risk." The objective of risk quantification in this case is to arrive at an estimate that describes the probability that a given residential single family unit will experience a post-earthquake fire.

- Risk quantification for a subdivision or an entire city. We call this type of risk the "regional risk." The objective of risk quantification in this case is to arrive at an estimate for the probability of fire extending to and covering an entire subdivision or residential community such as a mobile home park.

Although in both cases the regional earthquake intensity plays a major role, different sets of factors influence the risk in the two cases. Table 2 provides a summary of common factors used for risk quantification in each case.

Table 2. Major Factors in Risk Quantification

Type of Risk	Type of Fire	Major Factors Involved in Modeling
Residential Unit Risk	Isolated fire confined to one unit	Type of appliance, interior piping design, electrical system design, use of safety devices (e.g., metal strap to secure eater heater to wall).
Regional Risk	Fire spread to several units within a subdivision	Wind velocity, wind direction, distance between adjacent units, subdivision design in terms of layout and easy access to emergency rescue facilities.

Methods for residential unit risk quantification are presented in Mohammadi, et al., (1992) for both gas system and electrical system failure that may result in fire. For both systems, analytical methods are used to simulate the behavior of the system due to ground shaking. Risk of fire under normal conditions is then used as a basis to arrive at the risk upon the occurrence of an earthquake using extrapolation techniques. The model was then used to estimate the risk for San Francisco. Table 3 provides a summary of probabilities estimated for post-earthquake fire occurrence for a residential building in San Francisco. Considering the number of residential units in San Francisco, the risk is translated into 11 gas related and 8 electrical system related fires if an earthquake similar to the 1989 Loma Prieta Earthquake occurs. If safety devices for gas appliance are used, the number of gas-related fires will dramatically be reduced to only 1.

Table 3. Fire Probabilities for a Single Family Dwelling in San Francisco

Type of System Used	Annual Probability of Earthquake Fire
Gas Appliance (without safety devices)*	0.00372 - 0.036115**
Gas Appliance (with safety devices)*	0.00017 - 0.00023**
Electrical system (composed of wiring, connection boxes, receptacles, etc).	0.00053

* Safety devices include straps to secure water heaters, shut-off valves, etc.
** The range indicated considers the variety in the type of appliances (e.g. water heaters).

Methods for regional risk quantification have been reported in Scawthorn (1988); Scawthorn and Khater (1993) and Itoigawa and Tsukagoshi (1988). These methods provide estimates of potential for fire spread between buildings in a subdivision during a major earthquake. In most cases, the application of such information is in urban planning and design and in emergency response preparedness.

RISK MITIGATION

Fires following an earthquake constitute a major problem in urban areas. It is thus desirable to develop a mechanism to reduce the potential for fire development and to mitigate the associated risk. Measures taken to mitigate the risk can be specific to individual residential units or specific to a subdivision or local housing community. To mitigate the residential unit risk, the following measures can be taken:

- Use straps to secure gas appliances to the wall to avoid overturning during ground shaking.
- Use automatic shut-off valves to discontinue the flow of gas during an earthquake. The automatic shut-off valve is sensitive to vibration and stops the flow of gas with certain level of vibration.
- Avoid storage of flammable materials, piled-up old furniture, newspaper, etc. at areas with potential for ignition and fire.
- Consider the use of a new generation of interior gas distribution system made up of corrugated flexible stainless steel tubing for gas distribution system in the building. The system uses much less number of joints and fittings and has a smaller probability of failure (Longinow, et al, 1989).
- Avoid using heavily loaded extension chords for electrical appliances.
- Consider using shut-off switches to cut-off electricity at the time of an earthquake.
- Properly use sprinkler systems. The January 17, 1994 Northridge earthquake was the first event in the United States in which automatic sprinkler systems in large square footage buildings were subject to high levels of earthquake motion. Typical older sprinkler systems (pre-1970) consist of steel pipe with threaded connections and limited bracing. The newer systems have main connections with some flexibility and transverse bracing of mains. Proper use of a sprinkler system is necessary to reduce the probability of damage to the system. The damage to most older systems during the Northridge earthquake can be attributed to the lack of adequate bracing and failure at pipe connections due to excessive displacement and/or interaction with adjacent items. Sprinkle installed in the pendant position from piping above ceilings sheared in some cases. In other cases, pendant sprinklers which were installed in drop/false ceiling systems were pulled through the ceiling by the upward movement of pipes and punched holes in the ceiling during the downward movement. These failure scenarios suggest that for the sprinkler system to be effective as a means of risk mitigation, a proper design should be considered to reduce the probability of sprinkler system failure.

Measures to mitigate the risk of fire in a subdivision primarily depend on urban planning and design. The major steps that can be taken to mitigate risk are: (i) make an attempt to confine a fire to the place it started; and (ii) provide an easy access for fire fighting and safety personnel. Additional steps that can be taken are development of a plan for residents evacuation during fire, consideration for an easy access for water for fire fighting activities and proper urban planning and design to avoid areas with residential buildings closely spaced to one another.

USE OF RISK ANALYSIS RESULTS IN PLANNING AND DESIGN

Urban Planning and Design

The results of a risk analysis method are often presented in the form of an annual probability that a given facility will experience a post-earthquake fire. Alternatively, for a given earthquake scenario, the number of potential fires for various subdivisions can be estimated (Mohammadi, et al, 1992). These results are comparative measures and indicate the level of vulnerability of a subdivision compared with others in an urban area. The specific application of such results is in urban planing and in the development of an efficient strategy for emergency rescue efforts. Areas with substantially higher probabilities of post-earthquake fires should be developed with easy access to major expressways and should be provided with alternative supplies of water for fire fighting activities. The arrangement of individual units should consider the potential for most probable wind direction in the area to minimize the risk of flash-over fire. Certainly in such areas row houses, mobile home parks and congested clusters of residential units should be avoided.

Insurance Premiums

Another application of the results of the risk analysis is to make a comparative evaluation of various subdivisions and make adjustments in insurance premiums for areas that are subject to higher post-earthquake fire incidence. The methods described earlier for risk mitigation purposes can be used as incentives to adjust the premiums.

SUMMARY AND CONCLUSIONS

An overview of risk of post-earthquake fires and potential risk associated with such fires in urban areas is presented. Fire incidents following recent earthquakes in US and Japan are investigated and reported. The following conclusions are drawn:

- Post-earthquake fires constitute a major hazard in urban areas.
- By analyzing the sequence of events leading to an earthquake fire, methods to estimate probability of occurrence of such fires can be developed for those fires that are due to failure of gas or electric systems.
- Several simple measures can be taken to substantially reduce the potential for fires during and after an earthquake in residential buildings.
- To mitigate the risk for a subdivision, proper urban planning and design should be considered.
- The results of a risk analysis approach can effectively be used for urban planning and design purposes and also in developing policies pertaining to homeowner insurance premiums.

REFERENCES

Comartin, C.D., M. Greene and S.K. Tubbesing (1995). The Hyogo-Ken Nanbu Earthquake great Hanshin earthquake disaster January 17, 1995, Earthquake Eng. Res. Institute, Oakland, California, USA.

Earthquake Engineering Research Institute (1993). The Hokkaido-Nansei-Oki earthquake of July 1993, EERI Newsletter, Earthquake Engineering Research Institute, Oakland, California, USA.

Itoigawa, E., and I. Tsukagoshi (1988). Stochastic model for fire spread in urban areas based on fire brands effect, Proc. of 2nd Japan-US Workshop on Urban Earthquake Hazard Reduction, Earthquake Engineering Research Institute, Oakland, California, USA, 223-233.

Longinow, A., J. Mohammadi and T.A. Williams (1989). Analysis of risk associated with interior gas distribution systems, Topical Report, Gas Research Institute, Chicago, Illinois, USA.

Mohammadi, J., S. Alyasin and D. Bak (1992). Investigation of cause and effects of fires following the Loma Prieta earthquake, Report No. IIT-CE-92-01, Department of Civil Engineering, Illinois Institute of Technology, Chicago, Illinois, USA.

Scawthorn, C.G. (1988). Fire and hazardous materials following earthquake: US perspectives." Proc., 2nd Japan-US Workshop on Urban Earthquake Hazard Reduction, Earthquake Eng. Res. Inst., 234-243.

Scawthorn, C.G., and M. Khater (1993). Fires following earthquakes: conflagration potential in greater Los Angeles, San Francisco, Seattle and Memphis areas, Earthquake Eng. Res. Inst., Oakland, CA, USA.

Scawthorn, C.G., and M. Khater (1994). Fires caused by earthquakes: greater threat than many realize, NFPA Journal, My/June, 83-88.

Todd,D., Carino, N., Chung, R.M., Lew, H.S., Taylor, A.W., Walton, W.D., Cooper, J.D. and Nimis, R. (1994). 1994 Northridge earthquake, NIST Special Publication 862 (ICSSC TR14), National Institute of Standards and Technology, Washington, DC, USA.

URS Corporation. Risk of Earthquake-Induced Gas Fires in Residential Housing, Rept. to Southern California Gas Co., San Francisco, 1988.