POST-EARTHQUAKE FIRES: THE TICKING TIME BOMB

by Mark Kluver, P.E.

The tremendous loss of life and property caused in September by Hurricane Katrina has spurred government at all levels to reevaluate what more could have been done. The same reconsiderations of risk and appropriate levels of protection have followed other natural disasters. There are few parallels between preparing structures and infrastructure for a major hurricane and a major earthquake, but one similarity that emerged was the threat of multiple, simultaneous fires. The fires that broke out in New Orleans could not be extinguished by traditional means because of the loss of electricity and other conditions that made the water distribution systems unusable. Although the fires may only be a footnote to the misery and destruction caused by Katrina, the loss of water supplies and other obstructions to firefighting efforts in the wake of a major earthquake has the potential to pose a significant threat.

In 1980, the Federal Emergency Management Agency estimated that potential property losses resulting from a major earthquake in California could produce "the worst catastrophe to the United States since the Civil War." The 1906 San Francisco earthquake certainly provides evidence of that potential: a three-day post-earthquake conflagration was responsible for 80 to 95 percent of the total property loss. A similar conflagration occurred following a 1923 earthquake in Japan, resulting in over 140,000 fatalities and the destruction of most of both Tokyo and Yokohama. Again, estimates of property loss due to post-earthquake fires range as high as 95 percent.

Causes and Effects

The October 17, 1989, the Loma Prieta earthquake occurred on the San Andreas Fault in the Santa Cruz Mountains of California. Measuring 7.1 on the Richter scale, the temblor was of only moderate force compared to what is possible along that portion of the fault line. Even so, it was responsible for 26 fires in San Francisco, located more than 60 miles from the epicenter. One fire in the Marina District spread to several buildings despite the availability of two auxiliary water systems devoted specifically for firefighting, an extensive system of water storage cisterns and a fireboat—precautionary lifelines put in place in response to the devastating fire losses following the city's historic 1906 earthquake. The crux of the problem was some 67 breaks in water mains, which effectively eliminated water pressure in

Although the epicenter of the 1989 Loma Prieta Earthquake was 60 miles from San Francisco, it caused 26 fires including one in the city's Marina District that threatened to become a major conflagration. *(Photos courtesy of the San Francisco Department of Building Inspection and Mark Kluver.)*

Ruins of homes and businesses in Kobe, Japan, after experiencing three days of conflagration-size fires. (*Photo by Mark Kluver*.)

the area. Fortunately, the fire was contained thanks to the fireboat and the availability of 6,000 feet of hose to draft water from the bay.

Other moderate earthquakes have shown similar patterns of fire and the associated problems caused by the lack of sufficient water to fight them. On January 19, 1994, a magnitude 6.8 quake centered in Northridge, California, resulted in approximately 100 fire ignitions, 30 to 50 of which were considered "significant." A principal cause was natural gas leaks. Like the Loma Prieta earthquake, the wind was light and dry vegetation was not a factor so there were no conflagrations. Nonetheless, the area's major water supply systems were damaged and the resulting low pressure in the distribution lines hampered firefighting efforts.

On January 17, 1995, an earthquake of similar intensity struck near Kobe, Japan. Approximately 90 fires broke out within minutes, primarily in the densely built-up areas of low-rise, mixed residential commercial buildings in the central city. At least 85 of these fires spread to adjacent buildings and 10 were considered "super" in size (either approaching or reaching conflagration status). The Kobe water system sustained more than 1,700 breaks, cutting off water for firefighting within a couple of hours following the quake. Collapsed buildings and excessive traffic congestion further stymied firefighters' efforts. Subsequent research conducted at Kobe University indicates that 500 deaths were due to fire and that almost 7,000 buildings were destroyed by fire alone.

The Kobe disaster provides a good snapshot of many of the difficulties that must be overcome in responding to fires that occur as a result of earthquakes. The fire service must contend with providing non-fire related emergency services and prioritizing responses to multiple fires; poor access to emergency sites because of damaged roadways and traffic congestion, resulting in delays in response when fires are in their early stages; false alarms and damaged or inoperable alarm and telecommunication systems; and a lack of water supply at sites because of extensive damage to the municipal water system.

A National Risk

Approximately 15 percent of the U.S. population live in areas that have the potential for a major earthquake. Although Alaska, California and Washington have historically experienced the most damaging earthquakes, areas at moderate to high risk exist in a total of 41 U.S. states and territories. In fact, some of the strongest seismic disturbances recorded in the contiguous U.S. actually occurred along the New Madrid Fault—which extends along the central Mississippi valley from northeast Arkansas through southeast Missouri, western Tennessee and western Kentucky to southern Illinois—when a series of quakes that shook the region in the winter of 1811–1812 included three estimated to have exceeded 8.0 on the Richter scale. Areas of South Carolina are also at risk from coastal faults capable of causing significant ground motion. Considering the likelihood of water supplies being interrupted following a major seismic event, the potential for uncontrollable building-to-building fire spread should be a nationwide concern.

Ignition and Fire Spread Projections

The increased power of computers has improved our ability to project losses due to fire following earthquakes. Building on the pioneering work conducted by Charles Scawthorn, estimates of potential ignitions and fire spread have been created for several cities including Los Angeles; New York; Seattle, Washington; and Memphis, Tennessee.

A scenario prepared by Risk Management Solutions indicates that a modern-day reoccurance of the Great San Francisco earthquake (magnitude 8.3) could be expected to spawn six major fires and many smaller ones. Although the total number of wooden structures has been reduced since 1906, the denser concentration of multifamily dwellings is cited as contributing to estimated property losses in the range of $12–18 billion assuming a dry season event with average wind speeds (about 9 miles per hour)—more extensive fire damage would be expected under stronger wind conditions. The study also concluded that the vast majority of the post-earthquake fires would be left to burn themselves out due to impediments to the fire service.

Analyses of a major earthquake in Los Angeles, Seattle or Memphis also predict widespread fire damage and a strong possibility of conflagrations. Projected fire damages are

After the domestic and two separate underground fire service water systems experienced loss of pressure due to pipe damage, water had to be drafted from the San Francisco Bay by a fireboat to bring the 1989 Marina fire under control. (*Photo by Mark Kluver.)*

$6.5 billion for an event in the Southern California Newport-Inglewood Fault zone, $4.5 billion for the Seattle/ Puget Sound area and $2.6 billion just for the Memphis area of the New Madrid Fault.

Then and Now

Several months prior to the Loma Prieta earthquake, I prepared an article titled "Building Code Trends and the Danger of Earthquake-Induced Fires" that was subsequently published in the September–October 1989 issue of the International Conference of Building Officials' *Building Standards* magazine. The article addressed the possible impact that trends in building codes could have on fire losses due to post-earthquake fires. Three categories of buildings were discussed: residential, low-rise commercial and high-rise structures. Although the span of 16 years between 1989 and now is historically brief, intervening seismic events and research have both supported many of my previous conclusions and added new insights into others.

Residential Construction

My original observation that "the prominent earthquake threat to residential construction is conflagration"—defined as the spread of fires across several blocks or more—was borne out by both the 1989 Loma Prieta and 1995 Kobe earthquakes. As noted, a conflagration was averted following the Loma Prieta quake only because of the availability of a fireboat to draft water from the San Francisco Bay. The city of Kobe was not as fortunate. The use of fireboats to provide water from nearby Osaka Bay was not as effective because the Kobe Fire Department was faced with a much larger number of initial fires and did not have the larger, 5-inch diameter hose employed in San Francisco.

In my 1989 article, I cited "three conditions [that] appear to be necessary to bring fire to a conflagration stage: 1) High density combustibles, 2) Windy and dry conditions, and 3) Impaired firefighting capabilities." Considering the light winds at the times of both the Loma Prieta and Kobe earthquakes, it would appear that only two of those three conditions are necessary to raise the threat of post-earthquake conflagrations in residential areas, especially when there is a large number of individual fires.

Wildfires that occurred in the hills of Oakland and Berkeley, California, in 1991 were responsible for the loss of 25 lives and the destruction of more than 2,900 single-family dwellings and 400 apartment units. As recently as October 2003, several simultaneous wildfires in Southern California were responsible for killing 23 people and destroying more than 3,600 dwellings. Events like these provide strong anecdotal evidence that the potential for catastrophic fires following earthquakes in areas with closely spaced single-family dwellings is real and serious. That is why the continued use in some areas of building safety codes that permit combustible exterior wall surfaces and up to 25 percent of exterior openings to be unprotected without sufficient regard for minimum fire separation distances should no longer be considered acceptable—the *International Building Code*® contains more appropriate provisions.

Low-Rise Commercial Construction

In my 1989 article, I noted that "serious earthquake-induced fires—those that citizens are unable to suppress unaided and require the response of the fire department—are normally associated with commercial buildings." Data from the 1994 Northridge earthquake show that of the 77 recorded structure fires, approximately 60 percent were located in residential occupancies, which would place far less than 40 percent in low-rise commercial structures. Further, each of the fires in commercial buildings was confined to the building of origin. It appears that a similar experience resulted following the Loma Prieta earthquake. The commercial buildings destroyed by post-earthquake fires in Kobe were smaller, mixed commercial/residential use structures of wood or light steel construction. It is my opinion that this intermixture of industrial/commercial and residential uses in a single area and the traditional Japanese method of constructing wooden post-and-beam frames with little lateral resistance make Kobe of little comparative value with respect to commercial construction in the U.S.

There are several reasons why U.S. commercial buildings should exhibit better post-earthquake fire experiences in the future. Foremost is the steady improvement in seismic design. The progressive development of code provisions based on observation and study of the effects of earthquakes should result in fewer fire ignitions due to the increased resistance to collapse that has been built into all structures. In addition, more rigorous design requirements for non-structural components should provide better protection to electrical systems and piping for gas and sprinkler systems within buildings.

Another trend in commercial building regulations that many believe will have a positive impact on post-earthquake fires are local ordinances requiring automatic sprinkler systems. Such ordinances are more prevalent in the western states that have the greatest seismic risk. It may be expected that during light- and moderate-strength earthquakes, when the majority of water mains and sprinkler systems will remain intact, automatic sprinklers will reduce damage by extinguishing fires soon after ignition. As demonstrated during the Loma Prieta earthquake, however, this safety feature may not prove as dependable when earthquakes exceed the moderate range. A loss of water availability or pressure during larger seismic events due to breaks in water mains and distribution lines is likely to diminish the benefit of sprinkler systems. This risk is further exacerbated by the heavy reliance of many modern building codes on automatic sprinkler systems for fire protection in commercial buildings.

High-Rise Construction

Fire-loss data from recent moderate seismic events in California show no particular impact on high-rise buildings. Even reports on the Kobe earthquake, during which a number of high-rises suffered partial collapse, do not cite fire as a specific problem. Based on this evidence, is it reasonable to assume that similar outcomes may be expected following future major seismic events in the U.S.?

Although serious fires in high-rise buildings are rare, they are particularly difficult to control without substantial fire service resources. As an example, it required the efforts of a total of 383 firefighters to bring a 1988 fire in the 62-story Interstate Bank Building in Los Angeles under control—nearly one-half of the on-duty force of the entire city. The fire originated in an open-plan office area on the 12th floor and extended to the 16th floor, primarily via the windowed curtain walls of the building. Installation of a sprinkler system in the Interstate Bank Building (which had not been required when it was constructed in 1973) was approximately 90-percent complete at the time of the fire but had not been activated on the five fire floors.

As most readers will know, U.S. building safety codes have required automatic sprinkler systems in most new high-rise construction for more than 20 years and a number of major cities now require all existing high-rise buildings to be retrofitted with such systems. The presence of an automatic sprinkler system in high-rise buildings, however, may not be the panacea some believe. The editors of the American Society of Civil Engineers' *Fire Following Earthquakes* question the reliability of the complex array of elements in a typical high-rise sprinkler system, noting that one or more of the following elements may sustain damage during a major seismic event:

- the water service connection to the building;
- the secondary water supply tank;
- the fire pumps, including the emergency power fuel supply;
- the fire pump control panels; or
- The sprinkler risers, mains, branches or heads.

The editors, who include Mr. Scawthorn, detail multiple ways by which each of these elements may be rendered inoperable. For example, the function of a pump can be critically compromised if differential displacement between the piping anchorage and the pump location exceeds a few centimeters. In any case, pumps may fail to respond properly due to the fact that municipal electricity supplies often falter during moderate or greater intensity earthquakes, and diesel-driven emergency power sources are susceptible to an additional array of failure modes including damage to the batteries necessary to start their engines. In short, nearly all of the elements cited above must be professionally detailed for seismic considerations and properly maintained over the life of the building to assure a reasonable level of confidence in the reliability of the system.

Conclusion

In the conclusion of my original article, I stated that "the high risk associated with the phenomenon of earthquake-induced fire is not given the attention it deserves in today's United States buildings codes." Unfortunately, I can not report that my opinion on this matter has changed appreciably. Since 1989, several significant earthquakes have occurred which have demonstrated that despite steady improvements to the structural and life safety provisions of our building codes and standards, fires following earthquakes still pose a formidable threat.

(continued)

POST-EARTHQUAKE FIRES: *(continued)*

There is a direct connection between the mitigation of general fire risk and the mitigation of fire following an earthquake, and there is a wealth of evidence that general fire-risk mitigation is improved when fire safety provisions are not excessively dependent on a single system or feature. Although earthquakes, and therefore the fires that follow, are low-probability events, they are also high-consequence events which must be given careful consideration, especially in areas subject to moderate and higher seismic risk. That is why I regard the reliance of our current model building codes on automatic sprinkler systems—the operation of which are likely be impeded for any number of reasons following moderate and larger earthquakes—as a ticking time bomb. I understand that cost is always an issue, but I also believe that it is difficult to argue against demonstrably appropriate levels of redundancy when lives and exceedingly large property losses may be at stake. ◆

References

Evans, D.D., W.D. Walton and F.W. Mowrer, 1997, "Progress Report on Fires Following the Northridge Earthquake," National Institute of Standards and Technology, Gaithersburg, MD.

Hall, J.R., 2001, "High Rise Building Fires," National Fire Protection Association, Quincy, MA.

Federal Emergency Management Agency, 1980, "An Assessment of the Consequences and Preparations for a Catastrophic California Earthquake," FEMA, Washington, D.C.

Fire Following Earthquake, 2005, American Society of Civil Engineers, Reston, VA.

Kluver, M., 1989, "Building Code Trends and the Danger of Earthquake-Induced Fires," *Building Standards*, September–October, International Conference of Building Officials, Whittier, CA.

"Kobe Earthquake Case Study," last modified March 16, 2003, *www.zephryus.demon.co.uk/geography/resources/earth/kobe.html*, The Geography Site.

Mohammadi, J., S. Alyasin and D.N. Bak, 1992, "Investigation of Cause and Effects of Fires Following the Loma Prieta Earthquake" Illinois Institute of Technology, Chicago, IL.

Ren, A.Z., and X.Y. Xie, 2004, "The Simulation of Post-Earthquake Fire-Prone Area Based on GIS," *Journal of Fire Sciences*, 22(5), Thousand Oaks, CA.

Scawthorn, C., and M. Khater,1992, *Fire Following Earthquake: Conflagration Potential in the Greater Los Angeles, San Francisco, Seattle and Memphis Areas,* prepared on behalf of EQE International for the Natural Disaster Coalition, Washington, D.C.

Sekizawa, A., 1997, "Post-Earthquake Fires and Firefighting Activities in the Early Stage in the 1995 Great Hanshin Earthquake," National Institute of Standards and Technology, Gaithersburg, MD.

Steinbrugge, K.V., 1982, *Earthquakes, Volcanoes and Tsunamis*: *An Anatomy of Hazards*, Skandia America Group, New York, NY.

Wellington Lifelines Group, 2002, "Fire Following Earthquake: Identifying Key Issues for New Zealand," Wellington, New Zealand.

Mark Kluver, P.E.*, is manager of Regional Code Services for the Portland Cement Association (PCA) in San Ramon, California; an active member of several ICC chapters and the Structural Engineers Association of California; and author of numerous papers on building code subjects related to fire and seismic design.*