EARTHQUAKE FIRE
Kobe, Japan
January 17, 1995

FIRE INVESTIGATIONS
NATIONAL FIRE PROTECTION ASSOCIATION

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Errata

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4.4 Casualties

The figure given for the death toll should be 6,000 (six thousand), not 60,000 (sixty thousand)
1.0 Executive Summary

On Tuesday, January 17, 1995, at 5:46 a.m. (Japan Standard Time), a 20-second earthquake measuring 6.8 on the Richter Scale occurred near the Japanese port of Kobe, about 500 km (311 mi) southwest of Tokyo. The quake, which was an order of magnitude larger than the Northridge Earthquake in January 1994, killed more than 6,000 people, injured at least 30,000, and left more than 300,000 people homeless. More than 100,000 buildings were severely damaged or destroyed by the quake and the fires it caused. 148 separate fires destroyed 6,513 buildings and an area of 624,671 m² (0.24 sq mi). The total dollar loss, including damage to buildings, transportation systems, and other portions of the infrastructure, has been estimated between ¥13 trillion and ¥20 trillion (U.S. $147 billion and U.S. $200 billion).

This earthquake was the worst to hit Japan since the 1923 Tokyo-Yokohama earthquake, which had an estimated Richter magnitude of 7.9 and resulted in nearly 143,000 deaths, primarily due to fire. The last Japanese earthquake to kill more than 1,000 people was the Fukui earthquake in 1948.

Several factors influenced the spread of fire immediately after the earthquake and in the days that followed. For example, many of the structures involved were built of lightweight wood or bamboo covered with a thin layer of stucco that was not well secured. Even if a building did not collapse, it often lost its outer layer of stucco. When this happened, the underlying wood materials were exposed, creating a large combustible fuel load.

Many residential structures were not adequately reinforced laterally, which resulted in either significant damage or collapse. When a structure did collapse, it generally left a pile of very combustible material in the street in front of it. Because the streets in the Kobe area are narrow, these piles eventually ran together, resulting in continuous debris from one side of the street to the other. This allowed fires to spread uninhibited.

More than 50 percent of the fires that were identified as having been caused by the earthquake occurred three hours or more after the quake hit. This is significant because a number of these fires can probably be attributed to ignition sources that might have been prevented or controlled. For example, electrical service was sometimes restored without isolating damaged areas. People used open fires to warm themselves or to cook food, and some left candles at shrines. Some fires were started by arsonists.

Unfortunately, the Kobe water supply was compromised very quickly by a large number of breaks in the distribution system that rendered the entire water supply useless within hours. The 971 underground cisterns located throughout the city that were meant to be used for emergency fire fighting operations were either blocked by debris, preventing fire fighting apparatus from reaching them, or they were damaged and lost all their water through leakage.
As for sprinkler systems, local experts say that they are not commonly used. Even when they were, they were often so badly damaged that they were not functional. In one hospital that did have a sprinkler system, the fifth floor suffered a pancake collapse that rendered the entire system inoperable. Many high-rise apartment buildings were equipped with a number of standpipe systems, but the quake frequently offset these buildings at street level by several inches, and it is assumed that the underground piping was severely damaged.

The lack of water supply and the limited access via roadways caused by the widespread structural collapse severely hampered fire fighting operations. In several cases, buildings were saved by citizens who formed bucket brigades to stop fires from destroying them.

One factor that may have actually mitigated the spread of fire after the earthquake was the type of heating system found in many Japanese homes. Japanese families often use kerosene heaters, which they commonly turn off in the evening. Since the earthquake occurred early in the morning, it is assumed that many of the heaters had not been turned back on. This helped reduce the number of potential ignition sources.

Another mitigating factor was the wind speed, which was relatively low at the time of the earthquake and for the three days immediately afterward. This helped to limit the spread of fire.

Building design was also a significant factor in limiting fire spread in several instances. Three types of occupancies in particular fared well: gasoline stations, power substations, and schools. In all three, a combination of noncombustible perimeter walls, and a lack of penetrations in the structure or open areas surrounding the building helped limit the spread of fire.

This report deals with the fire and emergency response to the disaster. It is based on a number of sources, including the personal observations of Ed Comeau, Chief Fire Investigator of the National Fire Protection Association’s Fire Investigation Department. Comeau spent five days in Kobe as part of a multidisciplinary U.S. team that operates under the auspices of the UJNR (U.S.-Japan Cooperative Program in Natural Resources), coordinated by Dr. Riley Chung of the National Institute of Standards and Technology (NIST). The team’s 18 members were drawn from several specialties, including lifelines/geotechnical, buildings, fire, seismology/geology, and transportation. During the site survey, Comeau was teamed with Dan Madryzkowski from the Building Fire Research Institute, a part of NIST. The team obtained a large amount of fire-related information from Dr. Yoshiteru Muroasaki, a professor in the Engineering Department of Kobe University, who formed teams of graduate students immediately following the earthquake to survey fire-damaged areas in an effort to ascertain what had happened and to collate the data.
Although this earthquake has been referred to by several different names, including the Hanshin-Awaji Earthquake, the Great Hanshin Earthquake, the Hyogo-Ken Nanbu Earthquake, the South Hyogo Prefecture Earthquake, and the Kobe Earthquake, it will be referred to as the Kobe Earthquake for the remainder of this report.

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SOURCE: NIST
2.0 Background

2.1 City of Kobe

Kobe, the capital of Hyogo Prefecture, is located approximately 500 km (311 mi) west-southwest of Tokyo, adjacent to the Osaka Harbor on Honshu Island. Osaka and Kyoto are to the east, and Hiroshima is to the west.

The city, which comprises 546 sq km (211 sq mi), consists of nine wards situated on a narrow coastal plain to the south of Rokko Mountain Range, which it also encompasses. Downtown Kobe is about 4 km (2.5 mi) wide and 24 km (15 mi) long and is located at the western end of a major urban-industrial area that extends to Osaka and Kyoto. Kobe is part of a critical transportation corridor through which run major highway and rail transportation routes.

In 1994, the population of Kobe comprised approximately 1,500,000 people residing in more than 600,000 households. Because the earthquake damaged a number of suburban areas and the island of Awaji-shima, however, the number of people the quake actually affected was 4 million. A significant percentage of these 1,500,000 people include foreign nationals and the poor, who live in high-density population neighborhoods in the flat lands close to the harbor.

Kobe, which is Japan’s second largest port, is a major container shipping center through which approximately 30 percent of Japan’s commercial shipping passes. In addition to shipping and shipbuilding, major industries include rubber goods, shoes made of synthetic materials, chemicals, electronics, machine and electrical equipment, textiles, and refined food products.

The majority of buildings in Kobe have been built since World War II, as the area was extensively damaged by allied bombing. Rapid post-war development and economic growth, and the limited amount of land available for building, have driven property values in Japan to extremely high levels, resulting in the concentrated use of property. In most cases, the widespread coexistence of commercial and residential occupancies in Japanese cities results in mixed fuel packages, so that commercial or industrial occupancies with high fuel loads are often surrounded by residential structures. Much of the newer construction in Kobe and the port area is also built on soft, alluvial soil that is subject to ground failures, liquefaction, lateral spreading, and settlement during earthquakes—a significant factor in the extensive structural collapse that occurred during and after this most recent earthquake.

High property values have also driven architectural styles for both commercial and residential buildings, which are frequently tall and slender, and situated in areas crowded with other buildings. The high density of buildings and the concentrated use of land in Kobe resulted in narrow streets and access ways—some as little as 2.44m (8 ft) wide. Such narrow streets create several problems from a fire safety and rescue standpoint.
First, in order to negotiate the smaller streets, the fire apparatus has to be smaller than the apparatus normally used in the United States and other parts of the world. This limits the amount of water and equipment that each piece of apparatus can carry. Second, it is easier for fire to spread from one side of a street to the other because the combustible structures are so close to one another. Third, a collapsed building often obstructs a significant portion of the road or closes it completely. This not only creates access problems for fire and rescue personnel, but it also blocks access to fire hydrants and underground water cisterns.

2.2 Building Construction

In Kobe, there were generally two types of buildings: smaller buildings of three stories or fewer and high-rise buildings, although very few high-rise buildings were more than 15 stories tall. Construction of both types of buildings has been influenced by traditional Japanese architecture and building methods and by the evolution of seismic requirements in building codes.

There were also numerous traditional Japanese residential structures consisting of post-and-beam exterior walls with heavy clay tile roofs set in a bed of sand, thick clay, and mud mortar. These buildings had few interior bearing partitions; in fact, the partitions typically were sliding paper shoji screens.

Two types of residential construction, called shinkabe and okabe, are very susceptible to tremor damage. Shinkabe, the older of the two types, consists of post-and-beam vertical members with mud-filled bamboo latticework in exterior and some interior walls. In okabe, the bamboo lattice is replaced with thin, but wide, wood lath and stucco. Only mortise and tenon wood joinery are used to fasten
This is typical of the type of damage that was seen throughout the Kobe area. The stucco covering would fall off the structure, exposing the underlying lightweight wood.

wood members, and the use of nails and metal fasteners for connections is limited. The connections between structural members of a building are the points at which they commonly fail during an earthquake. The foundations of older buildings consist of stone or concrete, and, in newer construction, concrete walls.
In older construction, no waterproofing paper or wire mesh had been used to reinforce the stucco or mud infill. This lack of waterproofing often results in dry rot and water damage to wood structural elements, which in turn weakens them and makes them vulnerable to collapse.

Newer residential construction is similar to that found in southern California, a mix of post-and-beam and wood-frame construction with exterior sheathing and stucco and asphalt shingle roofing. The foundations of the newer Japanese buildings consist of stone or concrete and concrete walls. This type of construction can survive an earthquake far better than the traditional Japanese dwellings.\(^6\)

Smaller commercial and commercial/residential buildings are generally of wood- or light-steel-frame construction with walls of stucco, okabe-type construction, or masonry infill. A small mixed-occupancy building is typically two or three stories high with an open front on the ground floor covered by roll-up doors or plate glass storefronts. The ground floor is referred to as a “soft story” because no significant length of wall on the street side provides lateral support to the building.\(^7\) Foundations of these smaller buildings are generally composed of concrete, but they are not very deep.

Larger buildings of four stories or more are steel-framed structures of reinforced concrete or composites of steel and concrete. Older post-war buildings are typically constructed of reinforced concrete, while newer buildings have steel structural systems. A large number of buildings have steel frames with lightweight precast concrete panels. Quite often, buildings have structural irregularities, including offsets and set-backs.\(^8\)
2.3 Structural Failure Mechanisms

During an earthquake, the soft first story commonly fails, causing the building to collapse or resulting in permanent offset of the first story. Numerous small buildings in Kobe were built so close together that they pushed against each other, and entire blocks of buildings were offset due to a “domino” effect.

Many of Kobe’s residential structures also lost their stucco covering when the earthquake hit. This exposed their underlying structural members, which were made of lightweight wood or bamboo. Even if a building did not collapse completely and create a large debris pile, it presented a great deal of exposed combustible material.

Large modern buildings suffered varying amounts of damage. In one case, a nine-story building toppled across a major street, its penthouse slicing through the building facing it. Engineers found that buildings built to newer standards, generally endured, while concrete office and apartment towers dating from as recently as the 1970s failed. Large buildings commonly failed at building offsets or where their “footprints” or cross-sections changed. Quite often, a building story collapsed at the offset.

According to one source, approximately 60 percent of Kobe’s 210,000 structures collapsed or partially collapsed, and an additional 180,000 structures were partially damaged. It was estimated that 90 percent of these buildings were residential structures.

Police reported that 106,763 houses and buildings were damaged or destroyed. The heavy roofs of traditional dwellings, which have relatively little lateral
A vast majority of the buildings were constructed of lightweight wood with a stucco covering. The stucco covering was not held in place securely, so even if a building did not collapse, the protective layer of stucco would often “peel off,” exposing the underlying wood.

strength and weak connections, contributed to the structural collapse, resulting in the majority of fatalities. Modern housing with lightweight roofing systems suffered little or no damage, and large buildings erected after a “seismic code” of construction was introduced in 1981 fared much better than older buildings.

2.4 Fire Protection Features

Few buildings in Kobe were protected with automatic sprinklers. However, standpipes with hose for occupant use were common in larger buildings. To augment the pressure provided by the municipal water supply, some buildings had fire pumps that were manually activated by a button at the hose stations. Fire department hose connections were sometimes installed to supplement the water supply to the hose stations.

Some special occupancies, such as gasoline stations, were surrounded by concrete walls approximately 2 m (6.6 ft) high. These walls, topped with noncombustible shielding, are intended to reduce the exposure to surrounding property from a fire that begins within the occupancy. Passive fire protection in residential, commercial, and industrial occupancies included steel exposure shutters and wired glass in fixed sashes.

2.5 Transportation Features

Several major east-west rail and motor vehicle routes passed through Kobe, as did an extensive subway system and monorail. Among these railways was the “Bullet Train” or Shinkansen, that ran primarily within a tunnel through Rokko Mountain in Kobe and on an elevated viaduct at the east portal. Three other main
There were a large number of manufacturing shops located directly underneath the elevated railways. This created a significant fuel load.

Access to some of the underground water cisterns was through connections such as the one shown in this photograph. Other connections were located in the street under metal plates.

Rail lines ran on elevated embankments, viaducts, and overpasses, beneath which were located a variety of shops and manufacturing operations. These occupancies created additional exposures to the rail lines because they contained combustible and flammable products. The two major vehicle expressways, the Hanshin Expressway and the Harbor Highway, were primarily routed on elevated viaducts and bridges.
2.6 Water Supply

Kobe obtains its water from the city water system, which is served by 240 reservoirs at 119 sites. Most of the system is gravity-fed, although approximately 15 percent is pumped to higher elevations. The system supplies both homes and businesses, as well as the fire service.

Twenty-one of the supply sites have dual reservoirs, one of which has a seismic shutoff valve. In the event of an earthquake, the valve closes, protecting a portion of the reservoir’s water supply from leaking out of the system. This can reserve 30,000,000 L (7,926,000 gal) of water in all of the 21 reservoirs combined. The goal of the emergency planners was to provide the population with 3 L (0.75 gal) of drinking water per day for seven days.

The water is distributed to the reservoirs and the piping distribution system from surface supplies and treatment plants through a tunnel system that is 57 km (35 mi) long and carved through rock. Four thousand km (2400 mi) of pipe, made mainly of steel and ductile iron, were used in the distribution system. Conduits built or replaced recently have seismic-resistant piping and joints, and pipes in newer service connections are of high-impact vinyl.

There are 23,500 hydrants throughout Kobe, each with a 150-mm (6 in.) hose connection. These hydrants are located underground and covered by a plate mounted in the sidewalk or street. In addition to the hydrant system, a network of underground cisterns provides a static water supply. There were reportedly 971 cisterns, 628 of which were reinforced for seismic reasons, located on approximately every other block throughout the city. Each of these cisterns had a
The use of kerosene as a fuel for heating residences was prevalent throughout the area.

Heaters were also attached to the underside of tables with curtains attached to the edges of the table. This arrangement warms the user's feet and legs.

capacity of 10,000 L to 40,000 L (2,642 gal to 10,568 gal) of water. Some were covered by manhole covers, while others had above ground connections and valves that allowed fire apparatus equipped with hard suction hoses to draft from the cistern. Fire apparatus could also use the hoses to draft water from other water supplies, such as rivers.
Many of the apparatus used in Kobe had to be designed to fit through the narrow streets and alleys of the city. This limited the amount of water, equipment, and personnel that could be carried on any single piece of equipment.

Example of electric power lines which were damaged by the fires.

### 2.7 Electrical Power

Kobe’s electricity was supplied by the Kansai Electric Power Co., which had 141 hydroelectric plants, 21 fossil fuel plants, and 3 nuclear plants. The power was distributed through 1,271 substations over 12,480 km (7,755 mi) of transmission lines and 92,182 km (57,282 mi) of distribution lines.\(^4\)
2.8 Natural Gas

Natural gas was furnished by Osaka Gas through an underground pipeline 49,430 km (30,716 mi) long that was supplied by LNG storage facilities located at the Port of Kobe. Gas distribution could be controlled at various levels after an earthquake. Eight “Super Block” systems, each of which served about 700,000 customers, could be shut down remotely by telemetry, and an additional 55 blocks could be shut down manually. Sixty percent of Kobe’s homes also had seismic shutdown valves on their gas services; these were an integral component of the gas meter itself.13

Few Japanese homes have central heating, so portable and fixed space heaters fueled by kerosene are prevalent. Fortunately, it is a common practice to turn off these heaters at night before retiring. Therefore, there probably were not as many heaters in operation when the earthquake occurred early in the morning as there would have been had the quake occurred later in the day.

2.9 Municipal Fire Service

The Kobe City Fire Bureau, which provides fire, rescue, and emergency medical services, is composed of two departments, Fire Prevention and Fire Suppression, that oversee 10 divisions, a Fire Task Force and a Fire Academy. The fire bureau is housed in 11 fire stations and 15 branch fire stations. As of 1993, the fire bureau employed 1,298 career personnel and operated two helicopters, two fireboats, 196 vehicles, and 72 portable pumps. In 1992, bureau personnel responded to 812 fires that killed 19 people, injured 95, and burned 8,360 square meters (0.003 sq mi) for a total loss of ¥952,507,000. They also mounted 774 rescue operations during which they rescued 229 people. In 1993, the bureau responded to 814 fires.
In addition to the career operations, there are 11 volunteer fire corps consisting of 15 branch corps with 160 divisions, for a total of 4,000 members. This corps provides first response to fires, performs emergency evacuations and small-scale fire suppression, and provides support operations, such as directing emergency vehicles and traffic.

According to the Kobe Fire Bureau, each pumper had a flow rate of 500 lpm to 600 lpm (132 gpm to 159 gpm) and, if equipped with a tank, could carry 800 L to 1,000 L (211 gal to 264 gal) of water. Their standard attack lines were 55 mm and 65 mm (approx. 2-1/8 in. and 2-1/2 in.) in diameter. They had no large-diameter hose lines.

2.10 Building Codes and Standards

Building codes and standards had evolved in Japan in parallel to those developed in the United States. In 1924, the first base shear requirement of 0.1 g was established following the 1923 Kanto Earthquake. In 1948, the base shear requirement was increased to 0.2 g following the Fukui Earthquake. In 1971, detailing requirements for lateral strength/shear reinforcing followed as a result of the 1968 Tokachi Earthquake. In 1981, ultimate strength design added ductility considerations and included evaluation for risks such as story drift or eccentricity.

2.11 Earthquake Preparedness

At the time of the Kobe earthquake, Japanese earthquake preparedness was not as extensive as it might be assumed, based on the country’s past experience. A Kyodo News Service poll found that only 3 of the 12 large Japanese cities had disaster prevention programs that could adequately deal with a major tremor or with a quake whose epicenter was located near the city. These three cities were Sapporo in northern Japan, Kawasaki in the greater Tokyo area, and Kyoto in the Kansai region of western Japan. Tokyo itself was found to be inadequately prepared.

A major earthquake was not expected in the Kobe area since it is not located near a tectonic plate boundary. As a result, governmental agencies in Kobe were not as aggressive with regard to earthquake preparedness as they were in other areas.
Geological Profile of the Kobe/Osaka area.
Map of the harbor area showing the areas which had been created with artificial fill.

There were a number of buildings with noncombustible structural components. However, when the spreading fires impinged upon these structures, the contents frequently became involved, resulting in a total loss of the contents and severe structural damage to the building itself.
# JAPANESE FATAL EARTHQUAKES IN THIS CENTURY\textsuperscript{16,17}

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<thead>
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<th>YEAR</th>
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3.0 The Kobe Earthquake

3.1 Geological Aspects
Much of the land that the port area of Kobe was built on was reclaimed land, which settled significantly during the earthquake. Fill measuring 12 meters (39 feet) deep was placed in the water to create land areas. Much of the soil consisted of sand and was not compacted, which resulted in an event called "liquefaction" when an earthquake passes through the soil.

Liquification occurs in loose deposits of sand. When the shock wave from an earthquake passes through it, the sand turns into a fluid mass.

Twelve landslides occurred in the mountainous area around Kobe. The largest of these was one that killed 34 people next to the Nikawa-Yurion Filtration Plant.

The largest previous earthquake near Kobe occurred in 1916 and was a magnitude 6.1 temblor.

3.2 Weather
The average wind velocity during the three days following the earthquake was relatively low: It reached 2.6 m/sec (5.8 mph) on January 17, 3.6 m/sec (8 mph) on January 18, and 3 m/sec (6.7 mph) on January 19. The temperature ranged from 0°C (32°F) to a high of 8°C (46°F) over the three-day period, and the relative humidity was between 45 percent and 70 percent. The conditions, described as calm, cool, and moist, were significant factors in limiting the fire spread.
4.0 Fires

Between January 17 and 20, 148 fires were identified in the Kobe city area, although another source indicates 350 fires in the first two days following the earthquake. Data on these fires were collected immediately following the quake by graduate students of Professor Murosaki of Kobe University, who conducted site surveys and interviews to confirm the origins of the fires. They were able to confirm the actual ignition source of 69 fires; the others were listed as being of unknown origin.

Five hundred deaths were attributed to the fires, which damaged approximately 660,000 m² (0.24 sq. mi.) of the city and 6,900 buildings. However, it was difficult to determine the exact number of people for whom the fires were the primary cause of death. Many may have been killed by trauma during structural collapse, and ultimately caught in the ensuing fires.

The fire spread was limited primarily by wide streets and open spaces, noncombustible walls, fire-resistant building construction, and favorable weather conditions. The large number of simultaneous fires and the disrupted water supplies and blocked roads reduced the effectiveness of manual fire suppression methods.

4.1 Fire Activity

Based on an analysis of the “119” calls (the Japanese equivalent of “911” in the United States) received on the morning of January 17, 53 fires were reported between the time the earthquake hit at 5:46 a.m. and 7:00 a.m. Between 7:00 a.m. and 9:00 a.m., 13 more fires were reported. Before midnight, an additional 42 fires had been reported. And 40 more fires were reported during the next three days, bringing the total number of reported fires attributable to the earthquake to 148.

The area most heavily damaged by fire was the Nagata Ward, also known as Nagata-ku, on the west side of Kobe City, where flames raged through almost 50 percent of the total area damaged. Most of the buildings in the Nagata Ward were 50-year-old wooden okabe and shinkabe structures that were two stories high. Their collapse resulted in piles of thin, dry wood with large surface-to-mass ratios. The Nagata area also had mixed residential, commercial, and industrial occupancies, often in the same building, and many of the industrial occupancies were shoe factories that contained significant quantities of solvents and plastics. The Nagata Ward was the most densely populated ward in Kobe, with 10,985 people per square kilometer (28,451 people per square mile).

Of the 148 fires, more than half started three hours or more after the earthquake, which is a significant observation. This was due to a combination of factors, including the restoration of electrical service before damaged areas were isolated and the use of warming fires as the sun went down and temperatures began to drop.
The areas that were damaged by the fires were extremely widespread. Buildings that were not damaged in the fire zones either were equipped with a feature that stopped the fire from entering the structure, or, aggressive action was taken by the residents to stop the advance of the fire.
Fire spread was slow due to the prevailing weather conditions. At the time of the earthquake and for the days afterward, the wind speed was relatively low, so the primary mechanism of fire spread was direct flame impingement. Many fires spread beyond areas to which they might normally be expected to be confined across the large, continuous debris piles created when buildings collapsed into the narrow streets. Automobiles parked in streets, in alleys, or beneath residences also served to spread the fire. However, the low wind velocities and damp environment prohibited the spread of flying brands and failed to provide the fires with a high rate of ventilation.

Fixed fire protection systems and manual fire fighting operations were not significant in mitigating the fires that followed the earthquake. In fact, the residential areas had no automatic fire protection systems, and, according to local sources, sprinkler systems are not commonly installed in commercial or industrial buildings. Indeed, only two systems were seen during the site inspection. A number of standpipe systems did exist in such buildings as high-rise apartments, but it was uncertain whether they were operable. The visible piping appeared to be intact, but the buildings were set back from the street by several inches, and it was assumed that the underground water connection had been significantly damaged.

Some passive fire protection was very effective in stopping or limiting fire spread. Gasoline stations, electric power substations, and schools appeared to survive the earthquake and ensuing fires particularly well. In at least one case, an
Very few buildings observed had fire sprinkler systems. However, a number did have fire department standpipes and hose for occupant use. Nevertheless, the buildings were frequently set back from the street, and the underground connections were probably severely damaged.

The entire block was destroyed by fire with the exception of the gasoline station. Gasoline station lots are required to have concrete block perimeter walls approximately 2 m (6.6 ft) high and topped with noncombustible shielding to reduce exposure to adjacent structures from a fire in the gasoline station. In this case, however, the wall provided exposure protection from the adjacent structures.
Electric substations also have fire-resistive perimeter walls that prevent fire from encroaching upon them. Typically, these walls, which are less than 2 m (6.6 ft) high, contain no openings that might allow flames to pass through. Fires outside electric substations can seldom do anything more serious than blister building paint.
School buildings had perimeter walls. Unlike the bunker-like electric substations, however, they also had many unprotected openings, such as large windows and doors, through which fire could spread into the buildings. The fact that fire did not spread was due, in large part, to the playgrounds and other open spaces around the school buildings that, in conjunction with the fire-resistive walls, minimized the damage these structures suffered.

Fire destroyed many buildings with noncombustible exteriors, because the flames from burning buildings surrounding them and penetrated their unprotected openings, such as windows. Their proximity to fuel packages, such as parked cars, also increased their vulnerability to fire. A number of noncombustible buildings that might normally have withstood direct flame impingement were damaged structurally, which created avenues for fire spread. Once fire entered a structure, it was generally a complete loss.

On the other hand, a number of buildings with noncombustible exteriors displayed burn patterns from flame impingement, but they were not destroyed since their windows were protected by wired glass. In many cases, the wired glass was cracked from the heat but was not penetrated. Steel shutters also protected some openings.

On a larger scale, clusters or groups of buildings with noncombustible exteriors served as fire stops. Fires that started in combustible structures surrounding a fire-resistive building burned around that building, and fires burning near groups of fire-resistive buildings damaged only the buildings directly exposed. There was no evidence of fire spread from one fire-resistive building to another.
4.2 Mechanisms of Fire Spread

Many of the residential okabe and shinkabe structures collapsed after the earthquake, because their lateral support was inadequate, and many buildings with a soft first story were offset significantly. These failures created large piles of combustible debris that often extended from one side of the narrow streets to the other, creating large, contiguous, piles of combustible fuel. Adding to the prob-
lem were a number of automobiles parked either under buildings or near them. The combustibility of these vehicles created situations of severe fire exposure.

Due to their design, many buildings also lost their stucco coverings, resulting in the exposure of the underlying wood. This presented an extremely large fuel load that placed the buildings at risk when fire impinged upon it.

4.3 Ignition Sources

The fires that began shortly after the earthquake were ignited by a number of sources. For example, electrical service was sometimes restored before the damaged areas were isolated. People used open fires to warm themselves or to cook food, and some left candles at shrines. Some fires were started by arsonists. Many structures were also supplied with natural gas, although 60 percent of the meters had seismic valves that shut down automatically.

One factor that may have actually mitigated the spread of fire after the earthquake was the type of heating system found in many Japanese homes. Japanese families often use kerosene heaters, which they commonly turn off in the evening. Since the earthquake occurred early in the morning, it may be assumed that many of the heaters had not been turned back on. This helped reduce the number of potential ignition sources.

4.4 Casualties

The death toll from the earthquake exceeded 60,000, and more than 30,000 people were injured. Kiyoyuki Kanemitsu, director of Kobe’s International
The transportation infrastructure was severely damaged, critically impacting the ability of the rescue services to move throughout the city.

Piles of debris often filled the streets, creating continuous piles of combustible material that allowed fire to spread across what might normally be considered a fire break.

Department, said 89 percent of the people killed were crushed to death. For example, 49 hospital patients died when the floor above them collapsed, as it did in several of the older large buildings throughout the city. Another 10 percent died in fires, and 1 percent were struck by falling objects. The elderly were particularly at risk—more than half those killed were at least 60 years old. Elderly people tended to live in basement apartments to avoid stairs, and many were killed when their buildings collapsed. The death toll would have been higher if
the quake had struck while the Shinkansen (bullet train) was operating, instead of 15 minutes before its first run at 6 a.m.²⁸

It was estimated that between 300,000 and 527,000 people were displaced as a result of the earthquake. By January 1996, approximately 47,000 families were still living in temporary housing, with 1,600 camped in schools and parks.²⁹

The financial impact, including damage to buildings, transportation systems, and other infrastructure, has been estimated at US $100 billion. Neighboring Osaka, Japan’s second-largest city, will need $10 billion to repair its shattered infrastructure. Despite the large costs, however, Finance Minister Masayoshi Takemura said that the reconstruction efforts will have a positive effect on the economy over the longer term if they continue smoothly.

4.5 Rescue and Fire Fighting Operations

The damage caused by the earthquake would have overwhelmed the fire fighting and rescue capabilities of any well-equipped and well-trained modern fire service, and Kobe was no exception. Adding to the problem was the fact that only minimal staff were on duty at the Kobe Fire Bureau the morning of the earthquake, possibly because the previous day had been a holiday. And the tremendous traffic problems that arose following the earthquake made it difficult for off-duty personnel to report to their duty stations.

The extreme traffic congestion also hampered fire response. Main highways were heavily damaged or blocked by collapsed buildings and piles of debris and could not be used, and civilian traffic jammed the remaining roads. Several overpasses on the primary rail lines, which ran east to west, had also collapsed, limiting movement north and south. In addition, pedestrians crowded the streets to look for refuge or to search for relatives.

An engineer attending an international conference on earthquakes in Osaka when the disaster occurred flew over the area at about 1700 hours on the day of the quake and saw eight large fires burning from an altitude of about 300 m (1,000 ft). He saw no fire streams and noted that all the fires were burning freely. He also saw no fire apparatus near the large fires, although he could see some in other locations.

Also hampering fire response was a lack of water. In fact, water for fire fighting, including the water in the cisterns, was only available for two hours to three hours. Many of the cisterns were damaged, and access to many others was impossible, because the manholes covering them were buried in debris. In addition, 2,000 breaks were reported in the water supply distribution system, which meant that water was available only from small tank trucks.³⁰ Fire pumpers normally carry 800 L (211 gal) of water, and no tank trucks were available. A relay from a fireboat was tried but was unsuccessful, because the hose lines were too small.³¹
Increasing the severity of the situation, Kobe City Hall suffered a mid-level pancake collapse at the fifth floor where the water department and all of its records and computers were located. One of the department's two satellite offices was also out of commission, having caught fire and burned, leaving only one water department office available. As a result, officials did not have enough information to allow them to isolate the damaged sections of the water distribution system.

Some residents took matters into their own hands, forming bucket brigades to bring water in from rivers and school swimming pools. In one instance, residents protected a kerosene storage facility in their neighborhood by removing the debris that had fallen next to it and holding a fire line with buckets of water. In another, a father and son protected their home while the collapsed structure next to it burned. The house the two men saved had a perimeter wall, but it was less than 1 meter from the burning house next door. The father and son managed to save their home by dumping water from buckets they filled in a river two blocks away on the fire side of the perimeter wall to keep the flames from spreading to their home. It looked as though the fire would overrun the house, despite their efforts, when flame impinged on the second story, cracking wired glass windows, and burned the plastic eave troughs and downspouts. Fortunately, the wind shifted and the fire moved away from the house, allowing the residents to apply more water to the boundary between the house and the fire.

In any event, the large numbers of people trapped in buildings made rescue, rather than fire suppression, a priority. Many of the collapsed buildings were two-story dwellings whose first floors had collapsed, causing the second floors to either partially collapse or deform. Fortunately, these dwellings had a high level of survivability, because the collapses were often of the "lean-to" type that offered voids in which victims found refuge. And rescues from this type of building collapse did not require specialized tools or extrication equipment. In a number of instances, total collapse was actually avoided, because the buildings were jammed so close together that many of them leaned up against each other when they failed and supported each other in place.

According to the eyewitness reports provided by the U.S. rescue experts, however, priorities were not set for the rescue; and they coordinated in the most effective manner. For example, emergency shoring was not widely used during rescues, and minimal effort was made to cordon off areas around dangerous buildings where occupants often continued to live or to enter to retrieve their belongings. A month after the earthquake, a significant number of severely damaged buildings had yet to be removed or stabilized. A large aftershock would have had serious ramifications.

The Japanese government also declined several offers of assistance from foreign sources. One of the experts attending the earthquake preparedness conference in Osaka immediately began trying to coordinate the response of United States
Urban Search and Rescue (U.S. US&R) resources to the disaster. He gave both the governor of California and FEMA a report, and a number of task forces were placed on alert for deployment. However, none was called.

A rescue organization from Britain, the International Rescue Corps., also offered assistance and received permission to deploy a team of 15 to Kobe on Saturday, January 21—four days after the disaster. During their five-day deployment, they searched several buildings, but many of their operations were carried out independently and did not involve local coordination or assistance.

The earthquake brought out many noble traits among the survivors, such as patience, perseverance, and honor. More than 7,000 people registered as volunteers after the quake, and many more provided assistance without officially registering. There were almost no reports of serious crime or looting, although there was some evidence of arson or incendiary fires. Prices remained generally stable despite shortages and the devastation of stores and banks. One source estimated that nearly 227,000 people ended up in shelters in the Kobe area, and another 300,000 lived in tents in makeshift neighborhood relief camps. To combat the threat of an influenza epidemic among those living in the camps, the government made free inoculations available to all city residents.
5.0 Utilities/Infrastructure

5.1 Transportation

It was estimated that 60% of all of the bridges within the hanshin region were damaged in the earthquake. Twenty seven bridges were severely damaged. Some of the bridges were very long, elevated structures, measuring tens of kilometers in length.

Subway tunnels also collapsed in the earthquake.

5.2 Water supply

Immediately following the earthquake, earthquake valves closed on 18 of the 21 service reservoirs. Immediately prior to the earthquake, there was 338,455 m³ (89.3 million gal) of water stored. One day following the earthquake, there was only 94,606 m³ (25 million gal) available. In addition, power was lost to the Yodogawa River Pump stations for 15 hours, which reduced the flow in the Hanshin system from 6,000 to 1,000 m³/hr (1.58 million gal/hr to 0.264 million gal/hr).

It was estimated that 3/4 of the system was out of service following the earthquake, which affected 1,000, 000 households. Firefighting water supplies were exhausted within 6 hours.
The Water Department Main Office was on the sixth floor of the Old City Hall Building, which had suffered a pancake collapse, making it and the records it contained inaccessible. Another satellite office was partially collapsed, while a third office burned. Because of these three events, records, plans and maps were not immediately available and hampered the restoration process.

5.3 Gas Delivery System

The LNG terminals and the three gas distribution systems did not suffer any significant damage, despite being subjected to high levels of acceleration from the earthquake. None of the 490 km (304 mi) of trunk lines were damaged.

The 5,000 km (3,107 mi) of medium pressure lines also fared well. Only 90 repairs were required throughout the network, none of which was considered major.

The low pressure system, which distributed the gas at a pressure of 1.8 kPa suffered the greatest damage. There were 43,895 km (27,275 mi) of low pressure lines, which were comprised of predominantly steel pipe with threaded steel couplings. Approximately 5% of the system was composed of polyethylene mains and services, and this type of piping survived the earthquake with relatively little damage.

Gas was shut down following the earthquake in stages, and by 9:00 pm, gas service had been suspended to 836,000 customers. Approximately 74% of the customer’s services had intelligent meters that sense the acceleration created by an earthquake and shut off the flow. Reports indicate that these meters did work well.

5.4 Electric Power

Immediately following the earthquake, it was estimated that 1,000,000 customers lost power. By the evening of the 17th, the number of customers without power had been reduced to 420,000. However, there was an increase to 500,000 customers because of fires affecting the system.

Prior to the earthquake, 35 generating units were in operation. When the earthquake occurred, 12 units stopped. Eight of these 12 were damaged, while the other four were brought back on line.

There was some damage to the high voltage transmission lines, but service was temporarily restored within two days.

The distribution system had approximately 57,614,000 miles of lines. This system was extensively damaged by the earthquake.
5.5 Telecommunications

Three telephone central office buildings were damaged, but were restored by January 29th. One of the generators at a central office would not operate because of the loss of cooling water from the municipal water supply.

193,000 lines were damaged, and 100,000 of those were restored by January 31.

The biggest problem was that of the system becoming overloaded with people attempting to place calls. The call volume, on January 17, increased by a factor of 50 over the normal traffic load. This call volume dropped to 20 times normal traffic by the day following the earthquake. Restrictions on calls were imposed to prevent switch saturation, which was lifted by January 22.

In order to restore service, six mobile satellite units were utilized due to the damage to damaged towers. Eleven diesel generators provided power where needed.

The telephone company provided free telephone service within the disaster area following the earthquake. They set up 2,700 phone sets and 350 fax machines at 760 different locations.
6.0 Analysis

There is little question that the timing of the earthquake played a major role in reducing the loss of life. If it had occurred later in the day, while a greater number of people were on the roads, in high-rise office buildings, or on the trains and subways, the loss of life—and the demands on the rescue services—would probably have been much greater.

A significant factor contributing to the spread of the fires that followed the earthquake was the combustible, non-reinforced construction common throughout the city. When the buildings collapsed, they created large piles of debris that allowed the fire to spread uninhibited. Fortunately, the wind speed was relatively low at the time of the earthquake and during the days immediately following.

The fire services were hard-pressed to mount an effective attack on the fire for a number of reasons. The primary water supply was compromised very quickly, leaving very little for fire fighting operations, and the secondary supply system—the underground cisterns—was not effective, because the massive amounts of debris blocked so many of the cisterns. The debris—and traffic—also blocked the streets so that apparatus could not reach either the fires or any of the potential water supplies. Furthermore, alternative water distribution systems using either tankers or water pumped from static supplies were not established.

When citizens took it upon themselves to mount fire suppression operations, they were sometimes effective in limiting the fire damage. However, it appeared that these “ad hoc” efforts were not coordinated.

Building design played a role in both aiding and halting the spread of fire. Passive design features such as noncombustible construction, wired glass, open areas around structures, limited openings, and noncombustible fences and walls helped to limit the damaging effects of fire.
7.0 Lessons Learned

This disaster presented some unique aspects that have never been seen before, but it also presented a number of classic problems that appear again and again in similar situations. What can we learn from the experience in Kobe that can be applied elsewhere?

7.1 Water Supply

Either the maintenance of the primary water supply or the availability of an alternative water supply is of paramount importance when attempting to deal with an outbreak of fire following an earthquake. Although the Kobe city planners had hoped that the cistern system would serve as an emergency supply, it was quickly compromised by several factors.

Many of the cisterns were inaccessible because debris fell over the access plates in the streets. The same debris piles kept fire apparatus from reaching the cisterns, preventing them from establishing temporary water distribution networks using the hoselines and pumps from the apparatus. Following the Loma Prieta Earthquake of 1989, San Francisco established an alternative water supply by pumping water from the harbor to the fires. This is a viable option in a city with large static supplies, such as harbors, lakes, or rivers from which water can be drawn. Large diameter hose lines must also be available to transport the water.
7.2 Mixed Occupancies

A wide variety of construction types and occupancies throughout the city resulted in a mixture of fuel packages. For example, a highly combustible occupancy, such as a shoe factory, was sometimes located next to a residential structure, or even within such a structure. These high fuel loads fed the fires, allowing them to spread further than they might have otherwise. Thought should be given to isolating industrial and commercial occupancies from residential areas to reduce the potential risk to the population. Within existing industrial/commercial areas, additional consideration should be given to augmenting the primary and emergency water supplies and implementing passive fire-resistance design features, such as wider streets to serve as fire breaks, noncombustible construction, and wired glass.

7.3 Fire-Resistive Construction

Where it was used, fire-resistive construction played a significant role in reducing fire damage. Structures such as gasoline stations, which were designed to limit a fire to the station’s boundaries, were not affected by fires that encroached upon them from outside the property. The fire exposure of structures surrounded by large, open areas, such as power substations and schools, was also limited.

Buildings constructed of noncombustible materials survived fire exposure better than those built of combustible material, although combustible buildings did not play as significant a role in fire spread as the wood-frame, stucco-covered residential structures that are so common in Kobe. However, the interiors of a number of noncombustible buildings were totally destroyed by fire, even when the structure itself remained relatively intact. If the fire been unable to penetrate the building, the interiors might have survived fire exposure.

Consideration should be given to reducing exposure hazards from adjacent buildings. If such exposures cannot be controlled or mitigated, efforts should be made to limit the means through which a fire can enter a structure by using passive design features such as walls and wired glass in openings.

7.4 Accessibility

It was very difficult for the emergency services to move through the city following the earthquake because debris blocked many of the roadways, causing massive traffic jams. A city known to be the potential target of a major earthquake should make an effort to develop some means of moving personnel and equipment around the area or to increase the number of locations from which they can respond. This means that it is necessary to evaluate the damage after a quake rapidly to determine how best to deploy the available resources and to use those resources arriving from other areas.
The lack of accessibility also meant that the fire department had a difficult time reaching the cisterns.

7.5 Critical Facilities

Several critical facilities did not survive the earthquake intact. One was a hospital, which suffered a mid-level pancake collapse. Not only did this create a significant rescue problem in the building itself, but it eliminated the hospital as a facility in which to treat injured citizens.

Kobe City Hall was also severely damaged. In fact, the floor housing the water department, which housed all the computers and records that would have helped identify key components of the water distribution system and allowed officials to isolate specific damaged areas and restore service, was completely destroyed. One of the water department's satellite offices and all of its records were also destroyed by fire.

Vital facilities should be identified before an incident occurs, and efforts should be made to either secure them or make provisions for alternative locations. Copies of critical records should be kept in a number of secure locations that will be easy to reach after an incident.

7.6 Population Preparedness

Following any major catastrophe, the population must be prepared to survive on its own for a period of time, as rescue and relief services will be overwhelmed by the scope of their responsibilities. The population should be trained in basic survival techniques, such as first aid and rescue, and they should be expected to maintain a supply of emergency equipment that will allow them to survive until widespread, official relief efforts can be mounted.

This training and preparation will have the added benefit of providing a cadre of skilled workers that can be called upon to help with emergency services during a disaster. In Kobe, as in San Francisco in 1989, there were instances of civilians either helping the fire department with fire fighting operations or taking it upon themselves to form bucket brigades to stop the advance of the fire successfully.

7.7 Rescue Services Preparedness

The rescue services in a high-risk area should be rigorously trained and well-prepared. All personnel should be trained in specialized rescue techniques, such as those used by the U.S. Urban Search and Rescue (USAR) task forces, and plans should be made to move personnel and equipment through damaged areas. The extent of damage should be rapidly evaluated following a disaster to allow for the potential redeployment of resources to isolated areas, areas that have suffered an unusual amount of damage, and areas in which a high number of victims need to be rescued.
Provisions should be made for ensuring that the infrastructure supporting the rescue services survives intact. Critical facilities, such as fire and police stations, hospitals, and communications facilities, should be reinforced, or alternative facilities should be established to back them up in case they are damaged. Personnel in such facilities should be taught how to survive an incident so that they will be available to assist. Provisions should also be made to contact and deploy off-duty personnel effectively.
Plans should be made to coordinate outside resources with local rescue operations. In Kobe, a number of international rescue teams offered assistance, but the offers were turned down. Using such specialized resources and incorporating them into the local rescue operations would have provided additional capabilities.

7.8 Coordination of Activities

Any incident of this magnitude requires the coordination of a number of different agencies. Emergency services personnel frequently work with agencies outside their normal operating sphere, but a disaster such as the Kobe earthquake brings together a number of groups that are not used to working under such conditions. Efforts should be made to bring all these groups together and to develop incident management plans that will train all individuals involved to coordinate their activities effectively during such incidents. These plans, which must be practiced, should include not only the fire and EMS communities, but also law enforcement, public works, relief agencies, construction companies, and the medical community, among others.
8.0 Conclusions

There are several U.S. cities that are within potential earthquake zones, such as Seattle, Washington; Long Beach and San Diego, California; and Memphis, Tennessee; and Boston, Massachusetts that could draw some lessons from what occurred in Kobe. Particularly along the New Madrid fault area in the central United States, there may be potential problems if a significant earthquake should occur. What is of special concern is the fact that many of the buildings in Kobe were rebuilt following World War II. In the New Madrid area, however, this did not occur and there are a number of structures that pre-date this period.

There are a number of critical “lessons learned” from the disaster in Kobe that can be applied in the United States. The citizens of the Kobe area did not expect a disaster of this magnitude to strike, and therefore did not have a heightened level of preparedness, such as those living in Tokyo have. This is comparable to the situation observed in the central United States, where residents are not as prepared for the consequences of an major earthquake, as are those living in the southern California area, for example.

In addition, the structures and infrastructure system were not designed for the energy released by this earthquake and were severely damaged. The loss of critical facilities and housing had a major role in the loss of life and property following the incident. The long term impact of housing a large number of displaced citizens and providing for their care was a major stress on the local and national relief efforts.

The large number of specialized resources that are required to rescue trapped and injured people is something that has been identified in the United States and addressed through the development of a national Urban Search and Rescue Program. The results when such a capability is not available were seen in Kobe. Having specialized rescue teams, equipped and capable of rapid deployment, can play a critical role in the outcome of a major catastrophe.

The lessons that have emerged from the Kobe Earthquake can be taken and applied throughout the United States and countries. While there were certainly differences in terms of construction style and national response capabilities, the international community can observe and learn from the tragic loss in Kobe.
Appendices

NFPA Standards

Several NFPA codes, standards and other documents can be used to design structures or to develop plans to respond to disasters such as the Kobe earthquake:

NFPA 1  Fire Prevention Code
NFPA 13  Installation of Sprinkler Systems
NFPA 30  Flammable and Combustible Liquids Code
NFPA 30A  Automotive and Marine Service Station Code
NFPA 54  National Fuel Gas Code
NFPA 70  National Electrical Code
NFPA 80A  Protection of Buildings from Exterior Fire Exposures
NFPA 101  Life Safety Code
NFPA 110  Emergency and Standby Power Systems
NFPA 203  Roof Coverings and Roof Deck Constructions
NFPA 221  Fire Walls and Fire Barrier Walls
NFPA 295  Wildfire Control
NFPA 298  Fire Fighting Foam and Chemicals for Class A fuels in Rural, Suburban and Vegetated Areas
NFPA 299  Protection of Life and Property from wildfire
NFPA 471  Responding to Hazardous Materials Incidents
NFPA 472  Professional Competence of Responders to Hazardous Materials Incidents
NFPA 1201  Developing Fire Protection Services for the Public
NFPA 1231  Water Supplies for Suburban and Rural Fire Fighting
NFPA 1500  Fire Department Occupational Safety and Health Program
NFPA 1561  Fire Department Incident Management System
NFPA 1600  Disaster Management

Footnotes

2 EERI, p. xi.
3 Kobe City Fire Bureau Brochure.
4 EERI, p. vii.
5 EERI, p. 11.
6 EERI, p. 36.
7 A “soft story” is a story in which there is reduced lateral support in one direction, which can be caused by features such as large openings for garages or plate glass windows for store fronts. These structures are susceptible to racking when an earthquake occurs.
8 EERI, pp. 25-28.
9 This type of “soft story” is characteristic of housing in San Francisco. The first floor of many multi-story residential buildings is a vehicle garage with a large door on the street.

10 EERI, pp. 22-23.


12 EERI, p. 83.


14 Letter and message from Kansai Electric, 2/2/95.

15 Ballantyne.

16 EERI, p. xi.

17 Japan Times.


19 EERI, p. 1.

20 EERI, pp. 6-7.

21 Ballantyne.

22 Most of the description of the fire aspects of the earthquake have been excerpted from the fire section of the NIST report, which was prepared jointly by Madrzykowski and Comeau.

23 EQE.

24 Significant changes were made in the earthquake resistance requirements of the building code in the Kobe area in 1981. Buildings constructed after this date had a higher survival rate than those constructed before these changes were in effect.


26 While the loss of life in this earthquake is certainly significant, it pales in comparison to the Great Kanto earthquake of 1923 in which 128,000 people died as a result of the firestorm that occurred following that earthquake. “The Kobe Disaster: The January 17, 1995, Hanshin-Awaji Earthquake,” p 5. Buckle, Ian, and Shinozuka, Masanobu (paper presented at EERI conference).

27 According to an Associated Press story dated Saturday, January 13, 1995, 75 percent of the fatalities are attributed to being crushed or suffocated under the debris.

28 Due to the variety of sources providing information, some of the statistics may be inconsistent regarding the actual numbers that can be attributed to a particular source of injury that may have caused death.

29 IBID.

30 EQE.

31 EQE.

32 BFRL, NIST.

33 Ballantyne.
Survival Profile Studies

Based on epidemiology studies done after recent earthquakes, some scientific findings are emerging regarding the survival profiles of victims trapped or injured in earthquakes. Much of this data confirms that which rescue workers have known over the years, such as a victims highest chances of survival diminish greatly after 24 hours, chances of survival are greater in a wood frame structure than a concrete framed structure, etc.

One such study was done following a magnitude 7.7 earthquake that hit the Philippines on July 16, 1990. This earthquake resulted in 389 fatalities with 695 injuries. One of the more obvious results that emerged was that one would have a risk factor of being injured or killed in a concrete structure of 86, while an occupant of a wood frame structure would have a risk factor of 14.¹ In drawing parallels between this earthquake and Kobe, no consideration is being made of the construction types and building codes.

However, when one considers the type of collapse patterns that occur when the different structures fail, and the effort required to effect a successful rescue out of each type of structure, one can understand why the survival rate would be higher in wood frame structures for the following reasons:

1) The structural components to a wood frame structure are not as large and heavy as a concrete structure, therefore the exposure to heavy debris which can injure, kill or trap people is reduced.

2) Because of the lightweight components, rescue operations are easier and are often performed by citizens without specialized training or tools. It was observed that 80% of the rescues made in the Philippines earthquake were rescued by people using no equipment whatsoever, another 18% by rescuers using hand tools such as picks and shovel, while only 2% were rescued by rescue personnel using heavy equipment.²

The fact that most of the rescues were made by untrained, civilian rescuers is an important one. In Kobe, as in most earthquakes, the local rescue services are totally overwhelmed and are unable to reach all of the trapped victims immediately. In the Philippines, it was learned that the highest chances for survival for the trapped victims were for those that were rescued within the first hour, and then they dropped dramatically as demonstrated in the following chart:

<table>
<thead>
<tr>
<th>Time before Rescue</th>
<th>Number of Survivors</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;1 hour</td>
<td>197</td>
</tr>
<tr>
<td>1-12 hours</td>
<td>26</td>
</tr>
<tr>
<td>12-24 hours</td>
<td>7</td>
</tr>
<tr>
<td>24-48 hours</td>
<td>3</td>
</tr>
<tr>
<td>&gt;48 hours</td>
<td>2</td>
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The following observation was made by the team that visited the Philippines: “The results of the study also highlighted that most of the crucial and life saving rescue work was carried out by members of the local community. This supports similar observations in connection with the Mexico City, San Salvador, and Loma Prieta earthquakes. The earthquake destroyed transportation networks and communications lines, thus isolating Baguio, the most severely damaged area. For the first 24-48 hours after the earthquake struck, residents in this area had to fend for themselves. Foreign rescue teams with sophisticated equipment and trained dogs were only able to reach the disaster sites 48 hours after the first tremor, by which time 99% of survivors had already been rescued.” This is further reinforced by a study done of the 1988 magnitude 6.9 earthquake which struck Soviet Armenia and resulted in 25,000 fatalities and observations made following the Campania-Irpinia earthquake in Italy in 1980 where 93% of the trapped survivors were rescued within the first 24 hours.¹

That is not to say that there will not be any survivors after a certain period of time, as was dramatically learned in Korea when a department store collapsed, and survivors were removed from the debris after being trapped for two weeks. However, the chances for survival are greater, the sooner that a victim is extricated and receives definitive care. In order for this to occur, however, it is vital that the local citizens be prepared for a period of self-sufficiency and not depend solely on the organized rescue services for support due to the overwhelming demands on the system. Los Angeles City has recognized this and has organized provides training to its citizens in basic survival and rescue techniques.

²ibid., p 511
³ibid., p 512
⁴Annals of Emergency Medicine, August, 1990
Internet First Person Accounts

Immediately following the Kobe earthquake, extensive use was made of the Internet for relaying information to the world on the extent of the damage. Kobe University was located in the middle of the city's destruction, but many of its links with the Internet survived, and within a short time a number of first-person accounts were being posted.

Students from a high school in Japan were communicating with students at a high school in Washington State, sending personal accounts of their experiences. Similar to the way that amateur radios have been used in the past to link ravaged areas with the outside world, the Internet provided a window to the world. Casualty reports, situation reports, and specific inquiries were posted almost immediately. The communications links out of Kobe University survived relatively intact, and this served as a major point of contact.

In addition, information for NFPA's report was gathered from a number of different sources on the Internet. The city of Kobe has a home page from which documents such as the reconstruction plan were gathered. Kobe University posted a number of engineering surveys and evaluations that were utilized. Reports from organizations such as EQE were downloaded from the Internet as information sources.

The following account was posted on Compuserve.

The morning of the 17th January 1995 started for me at 5:46 am. Stefan, however, had been woken at 5:30 am by the sound of our new electric heater coming on. We normally get up about 6:00 am, but the apartment had been a bit cold so the day before, which was a bank holiday, we bought an electric heater with a timer to heat the place up a bit before we got up. Stefan says he remembers being relieved that it worked OK. He’d contemplated getting up to start making breakfast but decided to stay in the warmth of the bed and see how much difference the new heater made to the temperature of the room by normal getting up time. In fact it was a good job he did decide to stay in bed or he would have been in the kitchen when the earthquake struck and might have been far worse off, but more about that later.

The earthquake started with a gentle trembling, which was what woke me up. We often have minor earth tremors in Japan and I thought this was just one of those, but suddenly it got much worse. It was like a bang and then everything was being violently shaken around, as well as the side to side motion that I would have expected (had I expected an earthquake at all) there was a sort of piston-like up and down motion too. I hid under the duvet, Stefan rolled over to try and protect me, just as well he did or he would have been hit by the wardrobe that landed on the bit of the futon he’d been laying on moments later. We could hear the sounds of all of our furniture crashing to the ground, our bookcases and cupboards spilling their contents all over the floor, all of

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our crockery breaking as it fell from the shelves, various pieces of electrical equipment flying across the kitchen (if Stef had been in the kitchen he may have been hit by a flying rice cooker!) and all of the light bulbs exploding. The shaking seemed to go on for an eternity and we thought we were going to die but finally it stopped after about 20 seconds.

Our first thought was to stay in bed where it was warm until it got light when we would phone work, tell them we were taking the day off and start the clearing up. This was shattered by the sound of the alarm bells ringing out and the smell of gas beginning to fill the apartment. We had to evacuate, we stumbled out of bed over bits of furniture and screen doors and tried to find some clothes, but nothing was where it had been the night before. We eventually managed to find some things in the darkness and stumble to the door. We grabbed our coats and I found shoes but Stef couldn’t find any so he went out barefoot, and also barely able to see because he didn’t have his glasses. We thought it was going to be like a school fire drill where everyone mills around in the cold for a while until the gas main was turned off and then we would be allowed back in. We went down the stairs following other people from our floor. As we went down the state of the building got worse with large cracks being visible on the fourth and third floors. Then everyone stopped on the second floor, the stairs had apparently collapsed and people were clambering over the balcony and jumping to the ground. After getting out of the building and looking back we could see that it wasn’t just the stairs that had collapsed but the whole of the ground floor of the building. It was then that we realized that we weren’t going to be able to live in that apartment again and may not even be allowed to enter it again.

We wandered around the streets for some time trying to find out what we should do or where we should go but no-one seemed to know. It gradually got light although the horizon was also lit by the glow of fires. We were very cold and had no money or other documents like passports etc. so we reluctantly decided that we had to try and go back to the apartment to get warm clothes and things (and of course Stef’s shoes and glasses). Other people had obviously had the same idea as they were also going back in. It was really scary, and an aftershock while we were inside made us decide to grab what we needed and get out again as quickly as possible. Anyone watching must have thought we were mad risking our lives going back in to a half collapsed building but we were freezing.

After milling around a bit more we found an aid station that had been set up by Stef’s company in a furniture warehouse and sheltered there. It became obvious that we were going to be spending the night there so Stef went back into the building again to get blankets and duvets or we would have frozen during the night. We got our first food that day at midnight when some company employees brought cooked rice and tea. The night was dreadful, we got almost no sleep due to the sounds of babies screaming, men snoring and the almost constant stream of aftershocks.
The next morning we got another rude awakening. At 6:00 am it was announced over the radio that there had been a poisonous gas escape and that everyone should evacuate. We set off walking with all the possessions we had rescued but were eventually told the wind had changed direction and that we could go back to the shelter. Some more food arrived. One orange or one rice-ball per family. We were told that we were going to be evacuated to the west of Kobe as it was too dangerous to stay where we were. We thought that this might be the last time we would be able to go back into the apartment so Stef went in twice more to get some more clothes and some precious things like the wedding photo's. Coming out the final time we met some Americans who were in Japan for a conference on earthquakes that had started the day before and were having a ‘field trip’. They agreed to contact our families for us.

We were going to be evacuated by boat, but first we had to get to the harbour which entailed a one hour walk through the devastation that had been our neighbourhood. We also had to carry everything we had with us. It was a very traumatic experience. The boat was moored at the Kobe steel plant in Kobe which was devastated with broken pipes, twisted and broken roads and pieces of heavy equipment overturned. Getting on the boat was like stepping into another world or waking from a bad dream. Electricity, water, hot foods and television, with one thing on all channels. It was then that we first realized how extensive the damage had been. The boat ride took about two hours after which we were bussed to the male steelworkers dormitory in Kakogawa, west of Kobe and out of the earthquake zone. We were allocated one room per family and we have been living there since.

The biggest problem for the first two weeks was boredom with nothing to do and being unable to get anywhere. We received parcels from my work with books and shoes and other bits and pieces but we were still bored. Since then I've been going to work in Osaka. It takes about 5 hours to get there because of damage to the train tracks so I have to stay over in a Hall of residence from Monday to Friday. Stef goes in to work every day from Kakogawa so we only see each other at weekends. The first week I was back at work everyone was so relieved to see me that they had ‘welcome back Angela’ parties and my boss bought me a slap-up French meal. Stef got a much more subdued reception. The main difference being that I was the most badly affected person in my lab but there had been others in Stef’s lab that had come off far worse some even watching the only home they had ever known burn down before their eyes.

Since then we have been able to go back and retrieve most of our stuff from our old apartment. The building was made temporarily safe by the company and we went in to fetch the things we needed and other important things and pile everything else into boxes which the company would bring out for us. We made a night time mission in Stef’s bosses car to fetch some of the bigger
precious items including my computer. It had to be a night-time mission as the roads of Kobe get completely blocked with traffic after about 6:00 am so we had to get into Kobe, fetch stuff from the apartment and get out again before 6:00 am. We then went in again a few days later to put things in boxes. It was quite harrowing going back in and seeing everything in the mess that it had been left in three weeks before. It was also very smelly as the fridge had spilled its contents which had spent the next three weeks rotting. The boxes are now waiting to be delivered in a warehouse somewhere. We’ve also been looking for a new apartment but with 300,000 other people also homeless this is virtually impossible.

Angela Kukula