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FIRES FOLLOWING THE NORTHRIDGE AND KOBE EARTHQUAKES

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Abstract

Large fires following an earthquake in an urban region are potentially of catastrophic proportions - recent earthquakes such as the 1994 Northridge and 1995 Kobe earthquakes, as well as several rece® nt large non-earthquake conflagrations, including the 1991 East Bay Hills and 1993 Southern California wild fires demonstrate that this potential is still quite real. The Northridge and Hanshin events are strikingly similar in magnitude, ground motions, affected population, time of day and season and other factors (eg, for both events, total earthquake-related fires were about 110). However, Northridge resulted in relatively small post-earthquake fire losses, while Hanshin resulted in the loss of 5,500 buildings. The factors that contributed to this quite different outcome were primarily the performance of the water system, the traffic congestion, and the building density in Kobe versus Los Angeles. Mitigation of the fire following problem is complex, but involves a combination of increasing public and fire service awareness, improving water supply and other lifeline seismic resistance, and structurally upgrading the building stock. Several cities in north America, including San Francisco, Berkeley and Vancouver (B.C., Canada) have active programs to mitigate the fire potential following earthquakes.

THE 1994 NORTHRIDGE, CALIFORNIA EARTHQUAKE

The Northridge earthquake was the largest earthquake to occur within a US city in more than 20 years. Because the earthquake primarily affected only a limited area, this paper focuses on the experiences of two heavily effected fire departments, the Los Angeles City Fire Department and the Santa Monica Fire Department.

Affected Area and Fire Protection. The 4:31 AM January 17, 1994 M_W 6.7 earthquake was centered under the Northridge section of the San Fernando Valley area of the Los Angeles region. The event resulted in Modified Mercalli Intensity (MMI) shaking intensities greater than MMI VIII over approximately 700 square miles of the northern Los Angeles area, Figure 1. The population most heavily affected was in the San Fernando Valley, which is primarily protected by the Los Angeles City Fire

Department. Table 1 lists fire departments significantly affected by the earthquake, and their summary statistics (see Scawthorn et al 1994 for additional detail).

Response and Related Aspects in the Northridge Earthquake. Approximately 110 fires were reported as earthquake-related on January 17, as shown in Table 2. For Los Angeles City, Santa Monica, Pasadena, Burbank, and Glendale, the number of fires is shown as reported by each fire department's incident reports. These reports reflect initial assessment of the probable cause, and may or may not include all earthquake-related fires. Furthermore, what is counted as a single incident report may involve multiple structures. Lastly, in the case of mobile home parks, a single incident in some cases even involves multiple ignitions, since several mobile home parks had several fires, but were only listed as one incident, at one address. The major damage caused by the Northridge earthquake and the largest number of earthquake-related fires was concentrated in the San Fernando Valley. This area is served primarily by the Los Angeles City Fire Department (LAFD).

Los Angeles City Fire Department. The Northridge earthquake reportedly caused or was a contributing factor in 77 fires in the LAFD service area. These earthquake-related fires are located on the map in Figure 2. The 77 fires were among a total of 161 fires that occurred on the day of the earthquake. Earthquake-related fires predominate the calls for the first three hours. During the remainder of the day, the earthquake is a factor in almost one half of the fires. The presence of aftershocks, the shifting of damaged structures, and the turning off and on of utilities as a result of the initial shock had apparently caused new fires to occur. Structure fires predominate (86%) the earthquake-related fires. As noted above, each report of a mobile home fire may actually involve multiple structures, since a single report may have been written for an entire mobile home park consisting of multiple burn sites. Fires classified as "outside" include the incident on Balboa Boulevard in Granada Hills where ground movement broke gas and water mains beneath the street, igniting the escaping gas and causing fires in five surrounding homes. More than 70% (66) of the earthquake-related fires occurred in single- or multiple-family residences, as might be expected from the building stock that is typical in the San Fernando Valley. The major cause of ignition was electric arcing as the result of a short circuit, although gas flame from an appliance is also a recurring source of ignition.

The large number of dispatches at mid morning were mostly hazardous condition calls due to the reported leakage of natural gas. Hazardous condition dispatches and other public service assistance account for over 75% of the dispatches.

Water Supply. The Northridge earthquake effected the water supply for portions of the San Fernando Valley. Breaks occurred in at least six trunk lines and a large number of leaks occurred at other locations. The Department of Water and Power estimated that approximately 3,000 leaks were caused by the earthquake, including two lines of the Los Angeles Aqueduct. Pump stations and storage tanks also sustained damage. The damage to the system resulted in a water shortage that had to be made up by water tenders. LAFD reported lack of water pressure at hydrants in much of the west and north portions of the San Fernando Valley. Due to this lack of water pressure, LAFD resorted to drafting from alternative sources, including the large number of backyard swimming pools in the area. SMFD reports the water supply system for Santa Monica suffered no significant impairment as a result of the earthquake.

THE 1995 HANSHIN (KOBE), JAPAN EARTHQUAKE

Affected Area and Fire Protection. The 5:46 AM January 17, 1995 M_W 6.9 (JMA M7.2) Hanshin (official name: Hyogo-ken Nambu) earthquake was centered under the northern tip of Awaji island near Kobe, in the Kansai region of Japan. The event resulted in Modified Mercalli Intensity (MMI) shaking intensities greater than MMI VIII over approximately 400 square km of the Kobe-Ashiya-Nishinomiya area, Figure 3.

The Kobe Fire Department (KFD) is a modern, well-trained fire response agency, organized into Prevention, Suppression, and General Affairs sections, and a Fire Academy. The city is divided into 11 wards for fire protection purposes. KFD maintains 11 fire stations and 15 branch stations, served by 1,298 uniformed personnel. Equipment includes two helicopters, two fireboats, and 196 vehicles. Other equipment includes 72 portable pumps. Fire engines carry predominantly 50- and 65-millimeter hose; larger hose is not available except for drafting purposes. KFD has a civil disaster prevention program as well as a cadre of volunteer fire corps with about 4,000 members. This corps provides the first on-scene engagement of the fire, performing functions such as giving directions to arriving emergency vehicles and helping to guide people to safety

Response and Related Aspects in the Hanshin Earthquake. KFD had minimal staffing on duty at the time of the earthquake, possibly because the previous day had been a holiday. Initial actions included recalling off-duty personnel and responding to fire calls. Approximately 100 fires broke out within minutes, primarily in densely built-up, low-rise areas of the central city, which comprise mixed residential-commercial occupancies, predominantly of wood construction. Within 1 to 2 hours, several large conflagrations had developed. There were a total of 108 fires reported in Kobe on January 17 (Kobe FD, 1995), the majority being in the wards of Higashi Nada, Nada, Hyogo, Nagata, and Suma, Figure 4 (after National Fire Research Institute, 1995). Modes of fire reporting were unclear as of this writing, and fire response was hampered by extreme traffic congestion, and collapsed houses, buildings, and rubble in the streets. Because of the numerous collapses, many areas were inaccessible to vehicles.

Fire spread was via radiant heat and flame impingement, building to building in the densely built-up areas. The wind was calm, and fire advance was relatively slow. In a number of cases, fires were observed to have stopped at relatively narrow fire breaks (e.g., 10 meters) or, in at least one case, at a high-rise apartment building, probably as a result of active fire fighting. The final burned area in Kobe was estimated at 1 million square meters, with 50% of this in the Nagata Ward.

The Ashiya Fire Department reported 11 fires on January 17; nine of them were before 7:30 a.m. Distribution of the fires was along an east-west line about 1 kilometer wide centered on National Route 2. The total burned area for the 11 fires was about 4,400 square meters.

Water Supply. Fire water is primarily from the city water system, served by gravity from 30 reservoirs. Of these, 22 have dual tanks, with one tank having a seismic shutoff valve so that, in the event of an earthquake, one tank's contents is conserved for fire fighting. In this event, all 22 valves functioned properly, conserving 30,000 cubic meters of water, which, however, could not be delivered because of approximately 2,000 breaks in the underground piping. Kobe has approximately 23,500 fire hydrants, typically flush-mounted (i.e., under a steel plate in the sidewalk or street) with one 150-millimeter-diameter hose connection. The city has provided underground storage of water for disaster fire fighting in 968 cisterns, generally of 40,000-liter capacity, sufficient for about a 10-minute supply of a pumper. All engines carry hard suction, so that additional water can be drafted from Osaka Bay or the several streams running through Kobe.

Kobe sustained approximately 1,750 breaks in its underground distribution system. Water for fire-fighting purposes was available for 2 to 3 hours, including the use of underground cisterns. Subsequently, water was available only from tanker trucks. KFD attempted to supply water with a fireboat and relay system, but this was unsuccessful due to the relatively small hose used by KFD. The first author overflew the area at about 5:00 p.m. on January 17 and was able to observe all of the larger fires (about eight in all) from an altitude of less than 300 meters. No fire streams were observed, and all fires were burning freely—several with flames 6 meters or more in height. No fire apparatus were observed in the vicinity of the large fires, although fire apparatus could be seen at other locations (their activities were unclear from the air). Some residents formed bucket brigades (with sewer water) to try to control the flames.

Northridge/Kobe - Comparative Analysis

Several observations emerge from these two earthquakes, which are summarized in Table 3. Specifically:

> **Ignitions**: There were a significant number of earthquake-related fires in both events. In fact, the total number of ignitions is comparable - 110 for the Northridge event, versus 108 for Kobe City. Considering that the great majority of the 77 ignitions within the City of Los Angeles occurred within the MMI VII isoseismal, and that this area contains about one third of the total Los Angeles City population of 3.4 million, this equates to about 1 ignition per 14,719 population for the Northridge event. In the case of Kobe (population 1.5 million), the 108 ignitions equates to 1 ignition per 13,676 population. Thus, ignition rate is also comparable.
>
> **Response**: In the case of Northridge, ignitions were all brought under control within several hours of the earthquake. Furthermore, the resources of the Los Angeles region were sufficient to deal with all fire ignitions, as well as other emergencies, such as search and rescue, hazardous materials releases, etc. This is an excellent response, and is due to the large well-equipped fire service in the Los Angeles region, which has dealt with a large number of fires and other emergencies in the

last several years. The fire service in Los Angeles equates to approximately 1 firefighter per 1,338 population, while in Kobe this ratio is about 1/1,138, or quite similar. However, Los Angeles region is significantly larger than Kobe, so that **Los Angeles had more than four times the total resources of Kobe,** a significant difference.

Weather Conditions: Wind, humidity and other conditions were favorable in both cases and not a major problem.

Water Supply: In Los Angeles, while firefighting water supply failed in the heavily affected portions of Northridge, firefighters were able to avail themselves of alternative sources (e.g., backyard swimming pools). In Kobe, due to the more than 2,000 breaks in the underground water distribution system, the fire department was without water within several hours, and found it difficult to relay or otherwise obtain water for firefighting purposes. As a result, fire spread in Kobe was significantly greater than in Northridge, resulting in the destruction of perhaps 5,000 buildings in Kobe.

The 1994 Northridge and 1995 Hanshin earthquakes and associated fires reinforce the following points:

- Earthquakes in urban areas continue to cause multiple simultaneous ignitions, and degrade emergency response due to impaired communications, transportation and water supply
- These events are replicable, as shown by comparison of the 1971 San Fernando and 1994 Northridge events (Scawthorn, et al, 1995), and by comparison of the ignition rates and other factors in the Northridge and Hanshin events, providing some validation for simulation modeling and projections for larger events
- Under adverse conditions, large conflagrations are possible in modern cities, as shown by events in California (i.e., the 1991 East Bay Hills Fire, and the 1993 Southern California wildfires), and by the Hanshin earthquake in Japan.
- Projections for larger earthquakes in Los Angeles indicate perhaps 500 ignitions within several hours - the situation is worse in Tokyo.

This accumulation of experience leads to the conclusion that the potential exists for large conflagrations following a major earthquake in an urban area. Under adverse meteorological and other conditions, these conflagrations may burn for several days, replicating the events of 1906 in San Francisco, and 1923 in Tokyo. Extensive, well-drilled mutual aid systems are required, in order to mobilize large resources in response, but the deployment of these resources will be hampered by transportation difficulties and, perhaps most tellingly, **failure of firefighting water supplies.** Improvements in planning and infrastructure are absolutely essential to forestall this potential.

Table 1.
Fire Departments Affected by the January 17, 1994 Northridge Earthquake

Fire Department	Estimated Population (thousands)	Area (Sq Miles)	Number of Stations	Fire Fighting Personnel	Number of Engines
Los Angeles City	3,400	469	104	2,865	104
Los Angeles County	2,896	2,234	127	1,842	144
Ventura County	700	126	30	327	40 +/-
Santa Monica	97	8	4	100	5
Burbank	94	17	6	120	6
Pasadena	132	23	8	150	8
Glendale	166	30	9	167	9
South Pasadena	25	3	1	27	2
Beverly Hills	34	6	3	81	7
Culver City	41	5	3	66	5
Fillmore	12	2	1	9	1

Table 2.
Fire Following the January 17, 1994 Northridge Earthquake

Community	Number of Earthquake-Related Fires
Los Angeles City	77
Los Angeles County	~15
Ventura County	~10
Santa Monica	4
Burbank	0
Pasadena	1
Glendale	0
South Pasadena	0
Beverly Hills	1
Culver City	0
Fillmore	2
TOTAL	~110

Table 3
Hanshin and Northridge Earthquakes: Comparative Analysis

ASPECT	FACTOR	NORTHRIDGE	HANSHIN
Event	Magnitude (M_W)	6.7	6.9
	Date (winter)	Jan 17	Jan 17
	Time	0431	0546
Region	Population (MMI 8)	1~1.5 million	2 million
	Density (pop/sq km)	1,000~1,500	4,000
Ignitions	Number (total)	110	108
	Structural Fires	86%	97%
	Rate (MMI 7) **Ign/pop:**	14,719	13,676
Response	FD Communications	manual dispatch	
	Resources (ff/popul):	1,338	1,138
	Stations	104	26 (Kobe)
	Traffic Congestion	Minor	Major
	Mutual Aid	Available - not needed	after 10 hrs
Water	Water System Damage	Some	Total?
	Cisterns	Swimming Pools	946, mostly 40 tons (10 mins)
Wind		Calm	Minor
Gas	Automatic Shut-offs	? few %	70% - ineffective due to structl collapse
Spread		Minor	Major: 5,000 bldgs

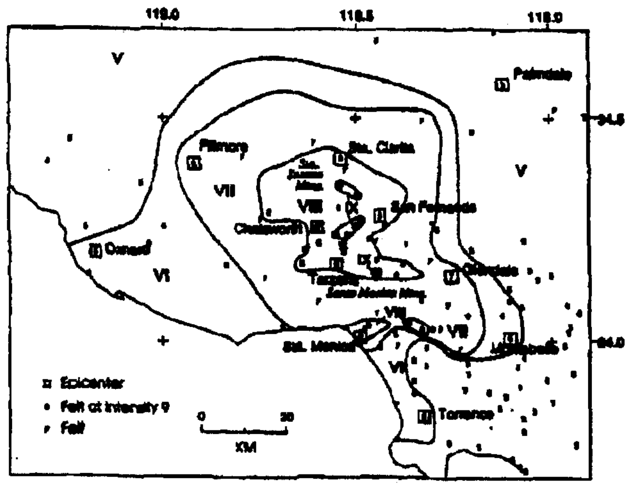

Figure 1. MMI Map for the January 17, 1994 Northridge Earthquake (from J. Dewey, USGS)

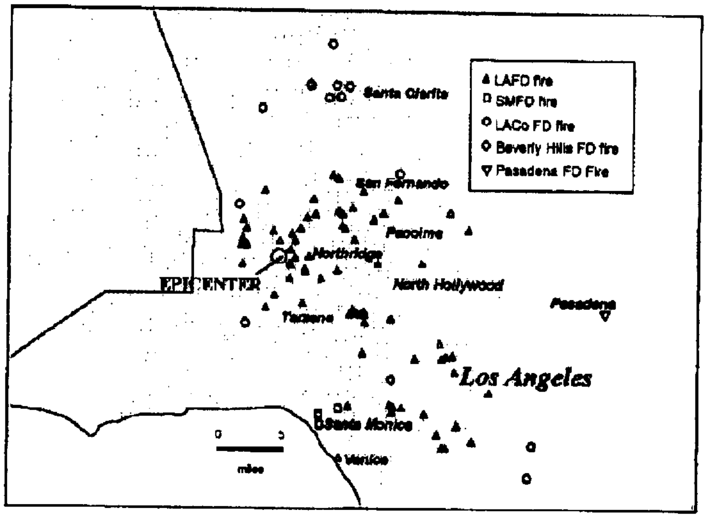

Figure 2. Earthquake-Related Fires, January 17, 1994, LA County Fires Only.

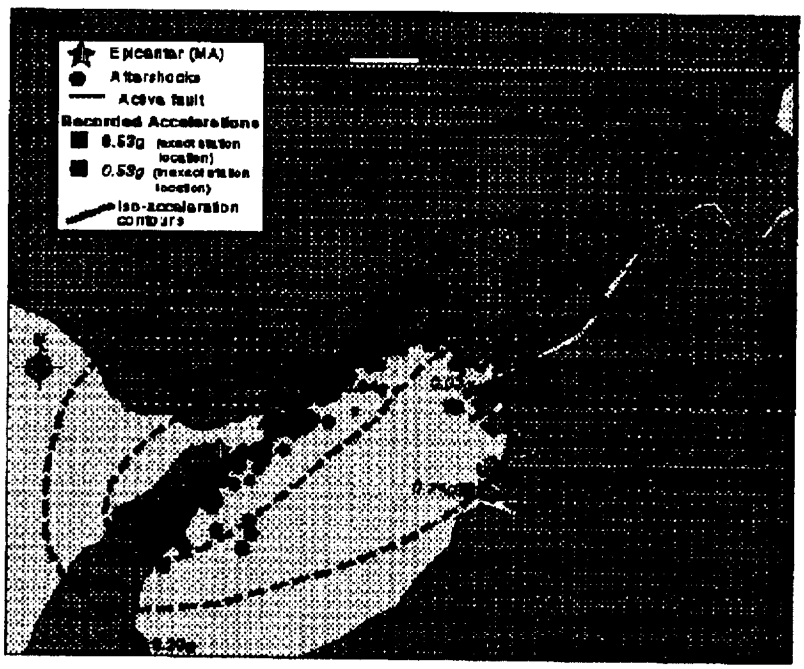

Figure 3. Shaking Intensity, Hanshin Earthquake (after EQE, 1995)

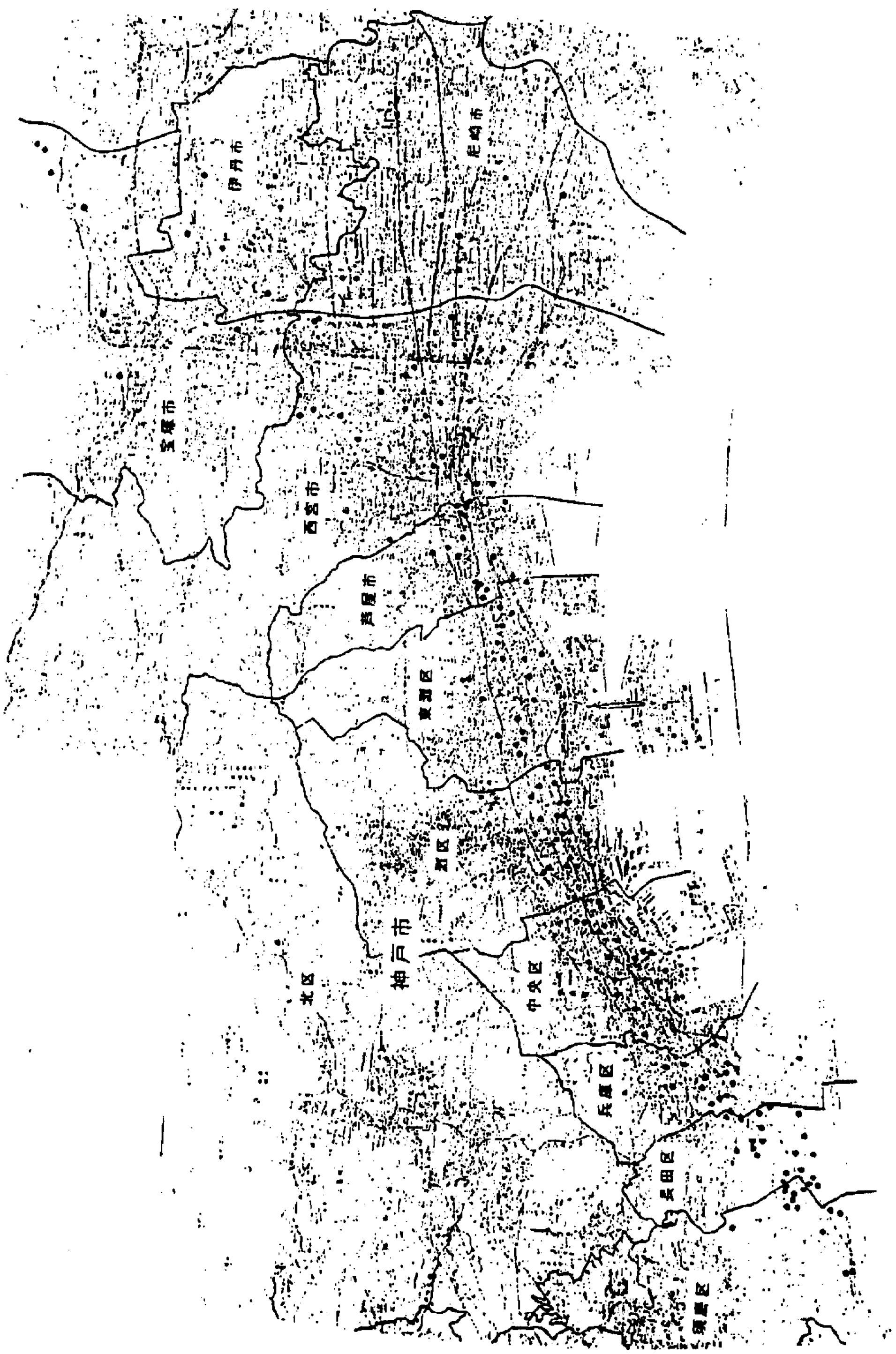

Figure 4. Ignition Distribution, Hanshin Earthquake (after National Fire Research Institute, 1995)

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Discussion

John Rockett: I have essentially the same question for you and the other speakers. There has been a great deal of interest in recent years in the extension of sprinkler systems to a wider variety of buildings. If one goes through the streets of Chicago, you see the remnants of old elevated tanks or the frames that they were on. It has become the philosophy that municipal water systems are so reliable that we don't need back-up systems. Do we need back-up systems for sprinklers in earthquake-prone areas?

Charles Scawthorn: I think the answer is case-by-case. You can't make a blanket statement. The Uniform Building Code presently requires for highrise and larger buildings in a seismic zone 3 and 4, which is basically the western United States, a minimum back-up water supply of about 15,000 gallons. That is precisely because of earthquakes. The lowrise building, say a warehouse, the building code would not require a back-up water supply within the building. It just takes it off the mains. When you lose pressure, the sprinkler system is going to be largely ineffective. In that situation, I think you have to look at the building density, the occupancy, and many other factors to decide whether a back-up is appropriate or you just want to rely on insurance and evacuation of people. I think that this kind of concept I just outlined falls under performance-based codes.

Ai Sekizawa:
Let me talk about the situations in Japan. As Mr. Scawthorn mentioned, there is a building code requirement that when buildings exceed a certain size, a sprinkler system or back-up water supply system is required. However, we experienced a problem at the time of great earthquake of Kobe. Many of those buildings that were equipped with back-up water supply systems had those tanks situated on the top of the building. Because of the earthquake shaking, the water tank was damaged, and the water in that tank escaped. Therefore, the actual system was not usable when needed. So we now need to work on ensuring the integrity of the tanks so that they themselves are seismic. Therefore, it is desirable to install those tanks underground rather than on the top of the buildings. In the case of Michiomia City, they had under ground tanks for the additional water supply, and they could successfully use that water when an earthquake happened. Therefore, their response activities were quite effective. That water supply is used not only for the fire of buildings, but also to extinguish fire in the streets or in the city or town.

Charles Scawthorn: Thank you for pointing that out Dr. Sekizawa. In the U.S., typically the pattern in a highrise building is that the water tank is in the basement and you have a back-up fire pump and back-up fuel supply in the basement. When the sprinklers trigger, then the pressure drops and the pumps kick in and utilize the back-up water supply. I think the entire system of back up motors, fire pump, piping and so on, can be improved a whole lot.