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Earthquake and Fire in Japan: When the Threat Became a Reality

When a magnitude 7.8 earthquake struck in the Japan Sea last year, it ignited a fire on the small island of Okushiri that destroyed almost 300 homes.

At 10:17 p.m. on July 12, 1993, an earthquake that measured 7.8 on the Richter Scale struck in the Japan Sea off southwest Hokkaido, the northernmost main island of Japan (see Figure 1). The earthquake and the resulting tsunami, or tidal wave, caused widespread, sporadic damage to northern Japan, with the heaviest damage occurring on the small island of Okushiri.

Located near the epicenter 19 miles west of Hokkaido, the island measures 6 miles by 12.5 miles and has about 5,000 residents who live mostly in three small villages. The primary occupation on Okushiri is fishing, followed by tourism; travelers visit the national park and volcanic hot springs on the western shore.

The earthquake and tsunami together left 182 people dead and 58 still missing and caused $60 million in damages. The tsunami alone resulted in most of the casualties and damages. The actual earthquake did relatively little damage to structures, but secondary damage from soil liquefaction and landslides was substantial.

Investigation team

In the days following the earthquake, a number of U.S. organizations expressed

San Francisco Fire Department released a report that identified problem areas encountered following the quake. The report found that:

- Personnel were not very familiar with the department's disaster operations plan or the city's disaster plan;
- Some of the apparatus were outdated and needed to be replaced;
- More equipment was needed, including hoses and search and rescue equipment;
- Transportation alternatives for recalled personnel were not sufficient;
- The water supply systems needed improvement. Breaks in the domestic mains in the Marina District severely hampered suppression operations–one 75,000-gallon cistern developed a leak and lost 20 percent of its water; and
- Disaster operations training that includes cross-training with city employees, the public, and fire department personnel was needed.

Despite all of the problems, the fire department of 1989 was better prepared for a disaster than the department of 1906. In 1906, fire stations were severely damaged, personnel were killed, the entire dispatch system was destroyed, and some apparatus were so badly damaged that they were useless. Fortunately, the department and the city learned from the destruction and made many needed changes. Once again, we have learned from our experiences. According to Chief Joseph Medina, the San Francisco Fire Department hopes to improve its suppression operations and, in general, be better prepared for the next inevitable earthquake.

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SANKAI SHIMBUN / SYGMA

Aonae, a small town at the southern tip of Okushiri, burns. Firefighters believe a kerosene tank that was overturned by the quake provided the fuel to start the blaze.

TABLE 1

Fire Department Account of Events

10:17 p.m.	Earthquake
10:20 p.m.	Firefighters leave station to look for fire
10:30 p.m.	See two ships burning in port
10:37 p.m.	See approaching wave, returned to station
10:40 p.m.	House fire reported; one pump and one tank respond (think kerosene tank overturned)
10:50 p.m.	Road blocked by debris; drafting from north cisterns
11:30 p.m.	North side under control; move pump to south cistern
12:45 a.m.	Second fire breaks out
12:50 a.m.	Clinic burns
1:30 a.m.	First and second fires merge
1:55 a.m	Move engines to south defense line
2:00 a.m. to 4:00 a.m.	Slow spread
4:00 a.m.	Cisterns dry; move to begin drafting sea water
4:00 a.m. to 5:00 a.m.	Clearing road to access seashore
5:00 a.m.	Begin attack with sea water
6:30 a.m.	Knock down houses to widen fire break
7:30 a.m.	Fire under control
9:20 a.m.	Fire extinguished

an interest in investigating the incident. Based in Oakland, California, and funded largely by the National Science Foundation, the Earthquake Engineering Research Institute (EERI) coordinates studies of earthquakes worldwide and arranges for the dissemination of the technical results of these studies throughout the United States. EERI members, who are some of the leading earthquake experts in the United States, cover all aspects of earthquake-related phenomena, including geotechnics, tsunami, structural and civil engineering, and fires.

The United States and Japan have a program of scientific exchange called the U.S.-Japan Panel on Natural Resources (UJNR), which includes a panel on Wind and Seismic Effects and a panel on Fire Research and Safety. Thanks to this program, a U.S. team representing EERI and UJNR was quickly organized by Noel Raufaste of the National Institute of Standards and Technology (NIST) and Kazuhiko Kawashima of the Public Works Research Institute (PWRI) in the Japanese Ministry of Construc-

tion. Raufaste and Kawashima are the respective chairs of the UJNR Panel on Wind and Seismic Effects.

The 12-member U.S. team, which included experts on geotechnical aspects, societal issues, tsunami, seismology, structural response, and fire, arrived in Tokyo just 6 days after the earthquake and joined a similar-sized team of Japanese experts. Cooperation was exemplary, and important data and observations were shared freely by a number of organizations, including PWRI, the Ports and Harbors Research Institute, the Building Research Institute, and the Fire Research Institute.

Earthquake and tsunami

The key feature of this earthquake is that it occurred along a subduction zone–an area in which one of the Earth's surface plates dives below another. Unlike the San Andreas Fault in Southern California, where one plate slides along the other, subduction faults are prone to build up more energy and then release it in a sharp, vertical motion of one plate. In this case, one plate was pushed up 8 feet along an area 93 miles long and 31 miles wide. This vertical motion of the sea bed caused the tsunami.

Japan has a tsunami warning system, similar to the U.S. Emergency Broadcast System, which broadcasts warnings over seven radio and television networks. Unfortunately, it takes about 5 minutes to initiate an alert, and the first wave struck Okushiri before the alert could be broadcast. Because Japan has a history of tsunami following major earthquakes, most residents ran for high ground as soon as the shaking stopped. However, the tsunami still caused most of the fatalities.

On Okushiri, wave heights averaged 33 feet, with waves in one area measuring more than 100 feet–the highest ever recorded in Japan (see Figure 2). By the time the tsunami hit the west coast of Hokkaido, the waves were less than 16 feet high and caused little damage. There were no fatalities on Hokkaido because the residents had received the tsunami warning and had evacuated the shore. Waves measuring 3 to 13 feet arrived on the coast of Russia 30 minutes after the earthquake, and 3- to 6-foot waves hit South Korea 90 minutes after the quake.

Aonae and its fire department

At the southern tip of Okushiri lies the town of Aonae, a fishing village with a population of about 1,500. Most of Aonae is located on a beach about 10 feet above sea level. The rest of the town, including a lighthouse, town offices, a school, and a fire station, is located north of the beach on a 65-foot central bluff. The lower part of Aonae is densely constructed, with narrow streets and buildings about 10 feet apart.

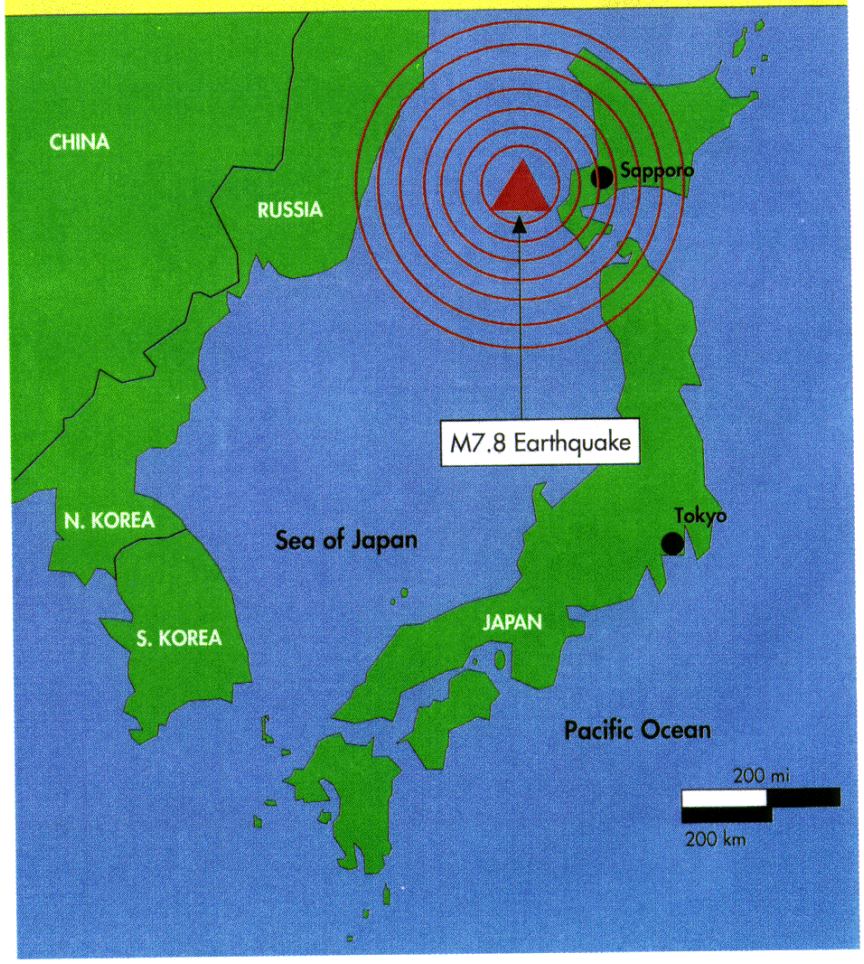
Most of the buildings are one or two stories high and are of post-and-beam, heavy timber construction, although there are a few steel and concrete structures. Most of the structures are covered with noncombustible cement board cladding over wood, with corrugated metal roofs. Because of the cold climate and construction type, there are no ridge or eave vents opening into the houses' attics.

Waves in one area measured more than 100 feet–the highest ever recorded in Japan.

Buildings near the wharf are mainly commercial, with residential structures located between the bay and the bluff. Many homes have adjacent storage buildings in which the owners, mostly fishermen, store nets and other supplies, including propane tanks. Most homes are heated by 130-gallon kerosene tanks, which are placed on a steel rack on cement blocks. These tanks, which are not anchored down, have a top vent pipe and a bottom feed through a filter and manual valve. In addition, each home has a pair of 44-pound propane tanks for cooking. These are normally not secured, either, except perhaps by a light chain.

The town is protected by a 38-member volunteer fire department headed by a full-time, paid professional. The department has two engines, each with a 525-gallon booster tank and 10 lengths of 65-foot, 2½-inch-diameter hose. The

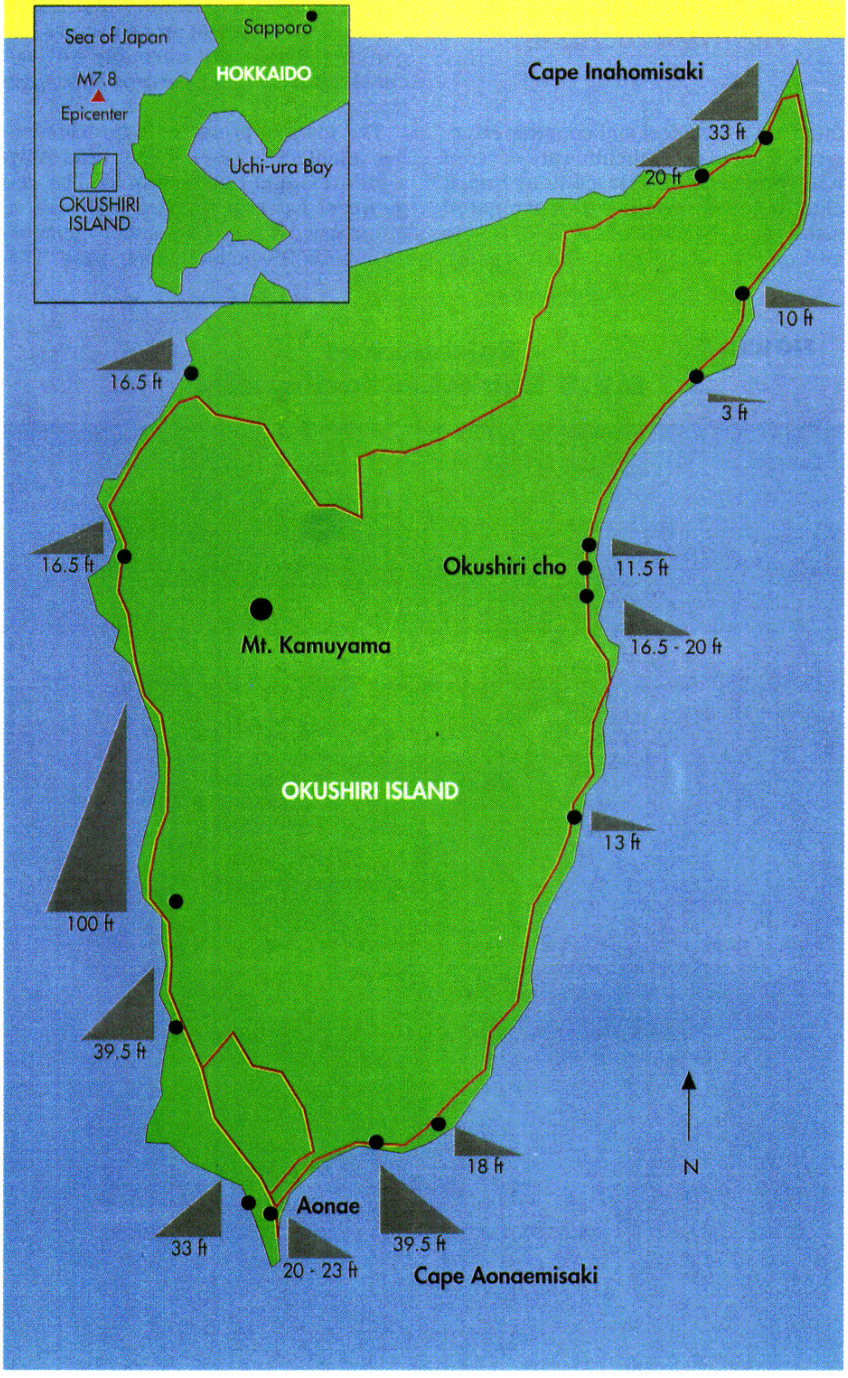
FIGURE 1 **Epicenter of M7.8 Hokkaido Earthquake**



engines can pump 680 gallons per minute. Each engine carries two 13-foot hard suction hoses with bamboo strainer baskets. The fire engines are smaller and lighter than U.S. engines, making it easier for firefighters to drive them through the narrow streets. A third engine was not in working condition and had been donated to the airport authority for reconditioning. It was parked at the south end of town and was destroyed by the tsunami.

Fire hydrants, which are located around the town, are not used because the water mains are not big enough and do not have enough pressure to provide adequate water for controlling a major fire. Instead, firefighters use booster tanks to control small fires, while the main water supply for fire emergencies is located in four underground 10,500-gallon cisterns, which are reached through concrete manhole covers.

FIGURE 2
Wave Heights from Tsunami Along Okushiri Coast



Immediately after the earthquake, Aonae received a mutual-aid call from another town on Okushiri, where a landslide had buried an occupied hotel, leaving 14 people dead and 10 missing. One engine and 10 men were dispatched to assist with the rescue efforts, leaving 1 engine and 10 firefighters in Aonae. The rest of the department members were out of town or otherwise unavailable.

And then came the fire

Shortly after the earthquake struck at 10:17 p.m., firefighters circled the village looking for fires. They saw two fishing boats burning at anchor in the bay, but they were not threatening any other property and eventually sank.

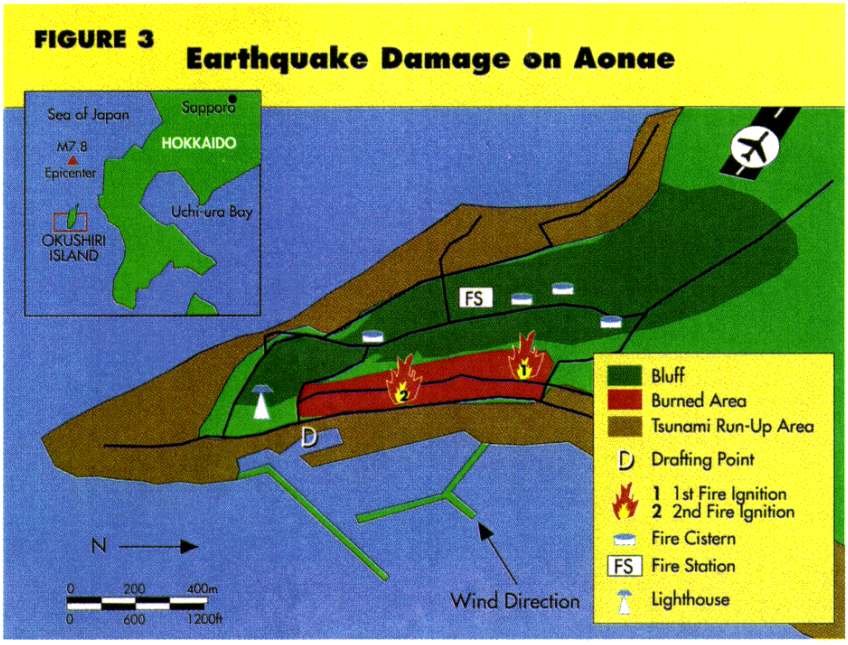
Fearing a possible tsunami–a major tsunami significantly damaged Aonae following a 1983 earthquake–the firefighters returned to the station. Within a few minutes, the wave struck, destroying buildings and spreading debris through the town.

At approximately 10:40 p.m., a villager ran to the fire station to report a house on fire in the lower village. A brigade of 10 men headed down the main road to the fire but found the road blocked by debris. They returned to the top of the bluff and took a second route to the south end.

The fire had begun in a structure north of the area directly affected by the tsunami. Firefighters believe a kerosene tank that was overturned by the quake provided the fuel that started the blaze, but they cannot be sure of an ignition source since the quake knocked out the power. Several villagers reported that the quake overturned all of their furniture, so numerous ignition sources, such as cooking and heating appliances, are possible. At the time of ignition, a 3.5-mile-per-hour wind was blowing onshore from the east and was gusting to about 11 miles per hour.

Firefighters began to fight the blaze using handlines from the engine parked on top of the bluff, drafting from the cistern near the fire station. The fire spread slowly south along the face of the bluff. Witnesses stated that every time the firefighters seemed to be gaining control, the fire would flare up again–probably because it was spreading to additional kerosene and propane tanks. Many such tanks were found empty after the fire; the kerosene in them had boiled over

FIGURE 3 **Earthquake Damage on Aonae**



through vent pipes, and the propane had vented through the pressure relief valves after their caps had melted. Vehicles parked near the houses added to the fuel load. Many old tires were found in the rubble, and there were reports that piles of scrap wood had been stored in the yards of many of the houses.

Fire spread was relatively slow, averaging about 115 feet per hour. Firefighters had been fighting the blaze for about 2 hours when a second fire broke out to their rear near the shore in an area that the tsunami had struck. Finding themselves between two fires, they took up a new position to the south of the second fire. An hour later, the two fire areas merged, and the first fire essentially extinguished itself as it reached the area burned by the second fire.

Again moving south of the fire, firefighters continued to attack the blaze, moving the engine to new cisterns as each one ran out of water. At about 4:00 a.m., 5½ hours after the fire started, they ran out of water in the last accessible cistern and decided to draft sea water. However, debris was blocking the road to the sea, and they spent an hour clearing the narrow road to the ocean using a bulldozer from a construction site. At this point, the advancing fire front was estimated to be about 300 feet wide.

Even with the new supply of sea water, firefighters were still unable to stop the fire completely. At 6:30 a.m., they knocked down two houses on the fire side of the road to widen the fire break. Within an hour, the fire was under control, and 2 hours later, it was declared extinguished. The fire was so close to jumping the street and consuming the remainder of the town that there was radiant heat damage to the exposed face of two homes just across the narrow street at the point at which the fire was stopped (see Figure 3).

Fire spread mechanisms

Exterior wood trim, the combustible contents of the houses, scrap wood stored between buildings, and kerosene and propane tanks all contributed to the fire spread. News videos taken of the blaze showed significant quantities of burning wood and embers flying through the air, but this did not play a major role in the fire spread because most of the buildings had metal roofs and there were no roof vents through which the brands could enter the attics. The fire spread because the buildings were so close together. Even in reinforced-concrete structures whose walls were still standing, the insides were gutted because the fire spread to interior combustibles.

Figure 4 compares estimated building-to-building fire spread in fires following earthquakes against observed data for 32 actual fires.[1] The equations account for wind speed, construction type, density, and primary method of fire spread. As the chart shows, the Okushiri fire spread more slowly than average.

Can it happen here?

There is a chilling parallel between what occurred in Aonae and several recent incidents in the United States which have not received the attention they deserve. For example, there were several fires following the Coalinga, California, earthquake on May 2, 1983, including a persistent fire in a collapsed building in the central business district. Although the water supply was not critically affected, fallen debris deflected hose streams so that firefighters could not extinguish the blaze as it spread to several additional buildings.[2] Only when an exposed, "down fire" building was knocked down by a large front-end loader could the fire be extinguished. Citizen volunteers played a significant part in controlling the blaze.

In the 1989 Loma Prieta, California,

The lower part of Aonae is completely devastated following the tsunami and the ensuing fire, which took approximately 11 hours to extinguish.

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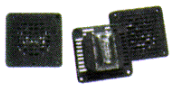

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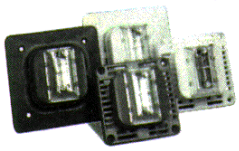

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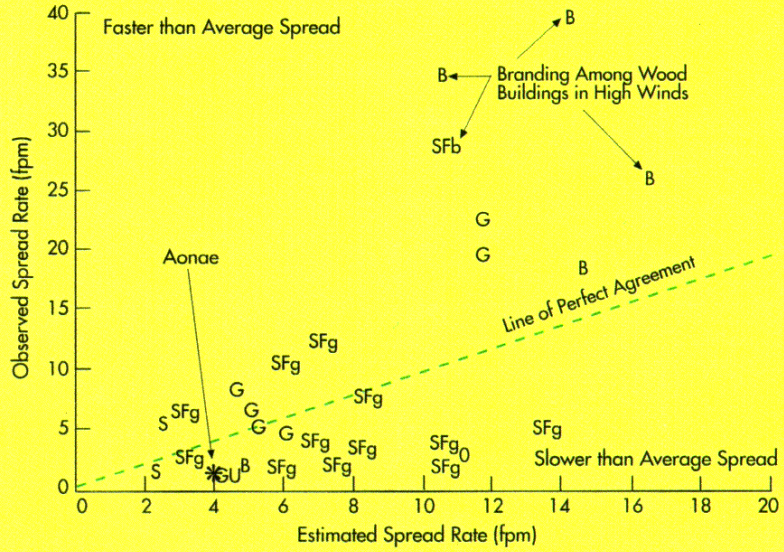
FIGURE 4
Fire Spread: Estimation vs. Observation
Method of Spreading



earthquake, 22 fires occurred in San Francisco alone. The water supply in the densely constructed Marina District was completely lost, and a large fire could not be extinguished until a fireboat supplied water from the bay through a special large-diameter hose system.[3] Again, citizen volunteers were of significant assistance.

On April 25 and 26, 1993, two earthquakes struck the Gape Mendocino area of Northern California, resulting in a blaze that destroyed most of the business district in the small town of Scotia. Broken pipes made the ordinary water supply inaccessible, and a special high-pressure fire loop could not be used because the earthquake had damaged emergency power units. In the same earthquake, damage to the fire station in Petrolia caused its doors to jam, and a fire destroyed the building next to the fire station before firefighters could respond.

Fortunately, we did not have to face the devastation of a tsunami in any of these cases. However, a subduction fault similar to the one in Japan runs through Seattle and into Puget Sound. If an earthquake of magnitude 7.8 struck there, a major tsunami would probably occur. How well would we cope with it? Put it this way. On Okushiri, the residents expected the huge wave and ran for high ground as soon as the shaking stopped. When a tsunami warning was issued for the northwest coast following an earthquake in Alaska during the mid-1960s, people actually drove to the shore to watch the wave!

The question is not whether a tsunami can happen here. The question is: Will we be ready for it?

Richard W. Bukowski is a senior research engineer and the head of the Fire Protection Applications Group of the Building and Fire Research Laboratory at the National Institute of Standards and Technology. He chairs the technical committee on Household Systems of the National Fire Alarm Code and is a member of the NFPA Signaling Standards Committee and several Life Safety Code *committees.*

Dr. Charles Scawthorn is a vice president at EQE International in San Francisco and is responsible for systems risk and research development. He has written more than 50 papers on earthquake risk analysis and mitigation. He is also a licensed structural engineer.

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2. C. Scawthorn and J. Donelan, "Fire-Related Aspects of the Coalinga Earthquake," *Coalinga, California Earthquake of May 2, 1983: Reconnaissance Report*, Report 84-03, EERI, Berkeley, Calif., January 1984.

3. C. Scawthorn and F.T. Blackburn, "Performance of the San Francisco Auxiliary and Portable Water Supply Systems in the 17 October 1989 Loma Prieta Earthquake," *Proc. 4th U.S. National Conference on Earthquake Engineering*, Palm Springs, Calif. 1990.