THE LOMA PRIETA EARTHQUAKE
San Francisco, CA
October 17, 1989

NFPA
INTERNATIONAL

FIRE INVESTIGATIONS

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FA-103/September 1991

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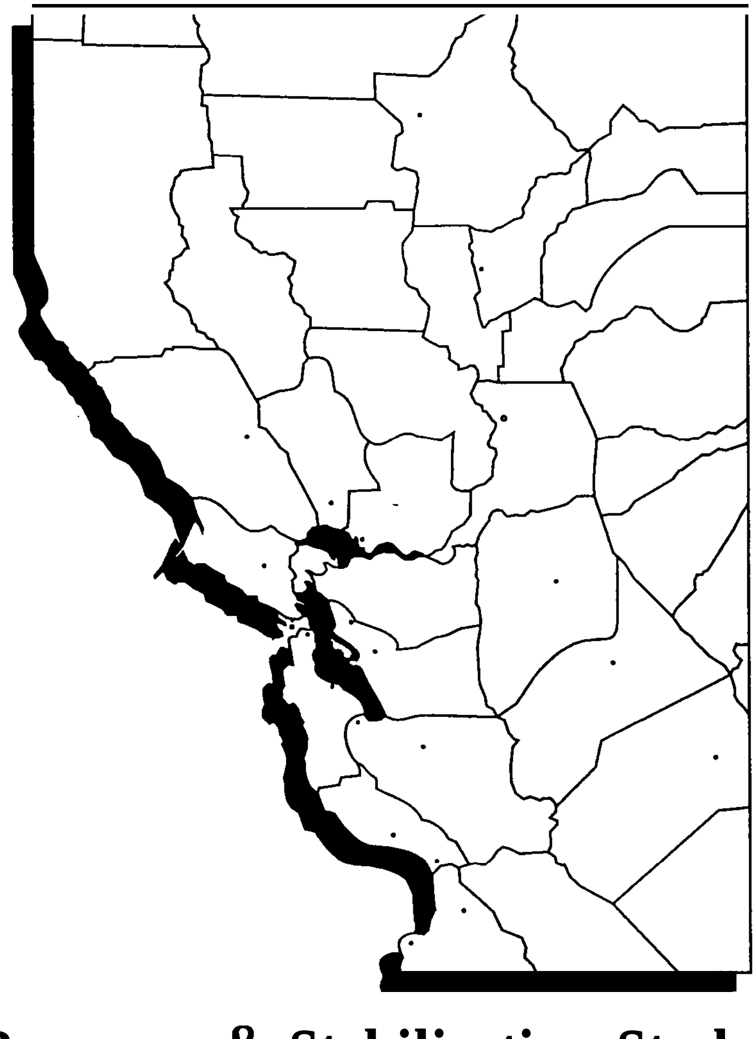

Emergency Response & Stabilization Study

Federal Emergency Management Agency
United States Fire Administration

The Loma Prieta
(San Francisco/Monterey Bay)
Earthquake
Emergency Response and Stabilization
Study

Prepared for the

Federal Emergency Management Agency
United States Fire Administration

Prepared by the

National Fire Protection Association
Fire Investigations Department

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EXECUTIVE SUMMARY

In the time it takes to read this sentence-about 15 seconds-an earthquake hit the San Francisco Bay area of California on October 17, 1989 and set into motion damaging and sometimes fatal effects that resulted in destruction over several thousand square miles (Figures 1 and 2). The earthquake, beginning at 5:04 PDT, was felt over an area of 400,000 square miles, with building damage across 3,000 square miles (Figure 3). A population of more than 7,000,000 was at risk.

Although San Francisco was hard hit and received the bulk of news coverage, the epicenter was 60 miles to the southeast, at Loma Prieta Mountain near the City of Santa Cruz. A 25-mile segment of the San Andreas fault ruptured at a depth of about 11 miles. The area had been recognized as having the greatest chance of producing an earthquake with a magnitude greater than 6.5 on the Richter scale of any fault segment in the region. This earthquake registered a magnitude of 7.1. It began without any seismic indicator in the days before the incident began that might warn of an impending emergency.

In the minutes following the earthquake, fire departments and other emergency response agencies in both urban and remote areas faced an overwhelming combination of events and challenges from the earthquake, including:

- Collapsed or damaged commercial buildings and homes
- Damaged government buildings, which hampered response and recovery efforts
- Collapsed or damaged bridges and highways
- Numerous injuries and rescue situations
- Simultaneous fires

- Ruptured valves and water lines, and damaged storage tanks
- Loss of electrical power and natural gas supplies
- Disruption of telephone communications and fire detection/alarm systems
- Impaired automatic tire protection systems over a widespread area
- Landslides blocking transportation routes
- Hazardous materials spills
- Numerous displaced persons
- Personal anxiety over the often-unknown safety or condition of family members.

These events placed maximum stress on the command and control systems of emergency agencies. Within the first minutes most jurisdictions in the damage zone responded to at least one major incident that had the potential to seriously deplete the available personnel and equipment resources. The advantages of preparation and planning soon became apparent. Local governments quickly implemented their disaster response plans. The state emergency operations center activated immediately after notification and was fully staffed within the first 30 minutes.

Because of communications difficulties, information was difficult to get and verify in the first hours and days, but the 15-second earthquake and related incidents produced these losses:

- 63 known deaths
- more than 3,750 injuries
- 12,000 people made homeless
- more than 23,500 buildings and residences damaged
- $6,800,000,000 in property damage
- $4,000,000 indirect business interruption loss
- Disrupted transportation, utilities and communications added to the psychological damage to individuals

In the 83 years since the devastating 1906 San Francisco earthquake and conflagration, only three earthquakes in the United States have registered a stronger magnitude than the Loma Prieta earthquake: in 1927 in Lompoc, California (7.5 Richter); in 1952 in California's Kern County (7.7 Richter) and in 1964 in Alaska (8.6 Richter). Loma Prieta retaught old lessons, especially the value of pre-incident planning and training for multijurisdictional emergency operations.

This earthquake was the most costly single natural disaster in United States history, but state and Federal officials acknowledged that this was not "The Big One" that is still expected to occur in California in the next 30 years. A future stronger shock or one located closer to dense population centers can be expected to cause much more extensive damage.

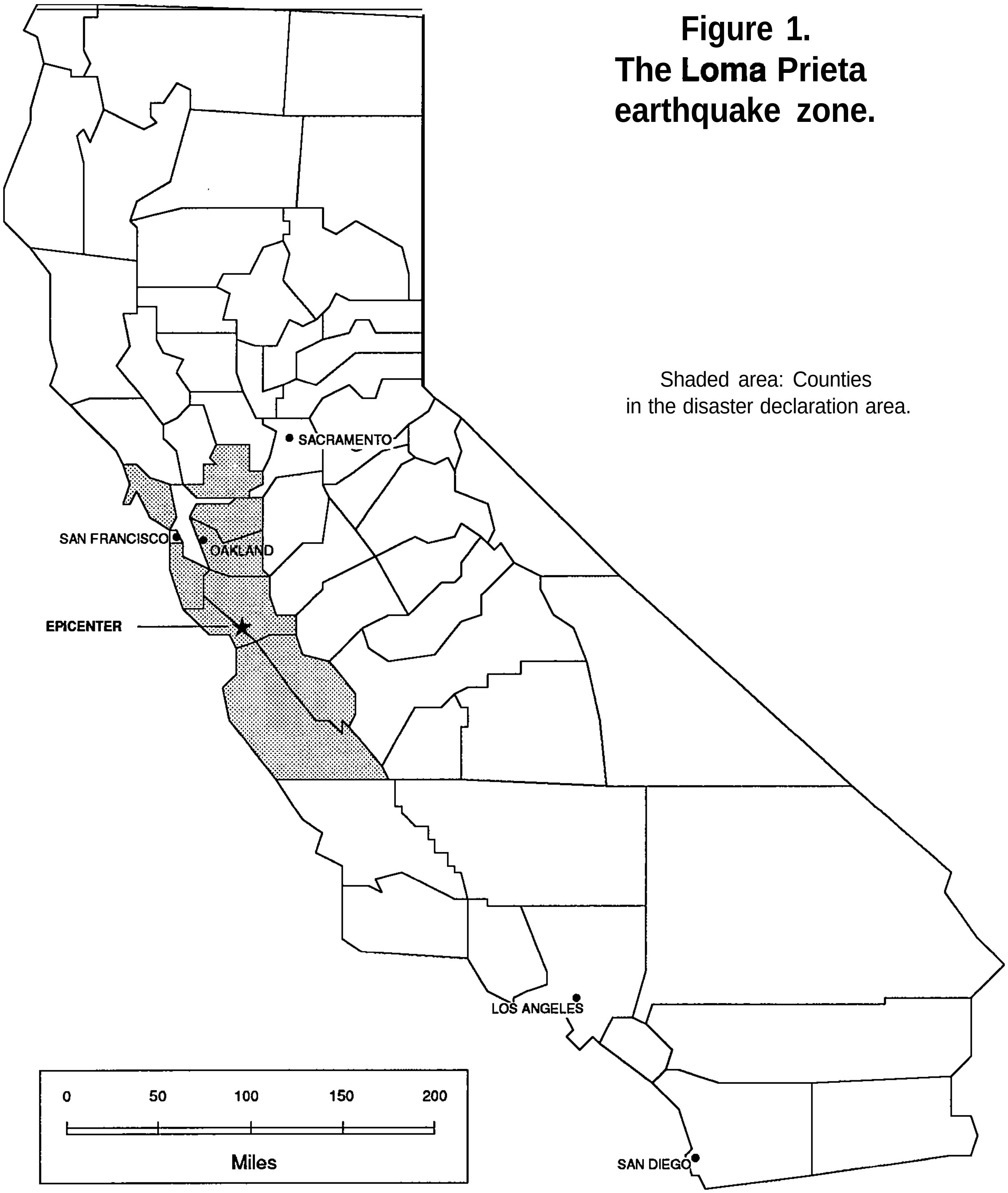
The initial emergency response to the Loma Prieta earthquake was very effective. Emergency crews within the state, cities and towns affected adapted response criteria and other emergency procedures to the numerous and immediate requests for assistance. These adjustments to their normal operating procedures did not occur by chance, nor did their individual coordination with county and state emergency organizations. Emergency responders in the State of California frequently cross jurisdictional boundaries responding to wildland fires, for example. When this does occur, management of the incident conforms to a system commonly referred to as an incident command system. Further, these same "first responders" are a vital component of the State of California's planning and training for earthquake emergencies. This preparedness also involves coordination with the Federal Emergency Management Agency (FEMA). As a result, the effectiveness of the emergency response could be anticipated with an earthquake of the magnitude of Loma Prieta.

Emergency response personnel within the state should evaluate their likely effectiveness if an earthquake of greater magnitude and closer to a population center should occur. However, the more serious concern to emergency responders in other parts of the country should be their abilities to function effectively during a major emergency. Earthquakes have been recorded in every state. Seismologists have said that geological conditions could produce a damaging earthquake in Alaska, along the New Madrid fault in Missouri, along the South Carolina coast, and in New York State.

If responders in other parts of the country lack the familiarity of crossing jurisdictional boundaries and cannot communicate effectively with other cities, towns, counties and state agencies, then less severe disasters than the Loma Prieta earthquake will have much more devastation in terms of life loss, injury and property damage.

Clearly, the emergency response to the Loma Prieta earthquake by the emergency services of the State of California was a success; the lesson learned from this success is preparedness.

Figure 1.
The Loma Prieta earthquake zone.



Shaded area: Counties in the disaster declaration area.

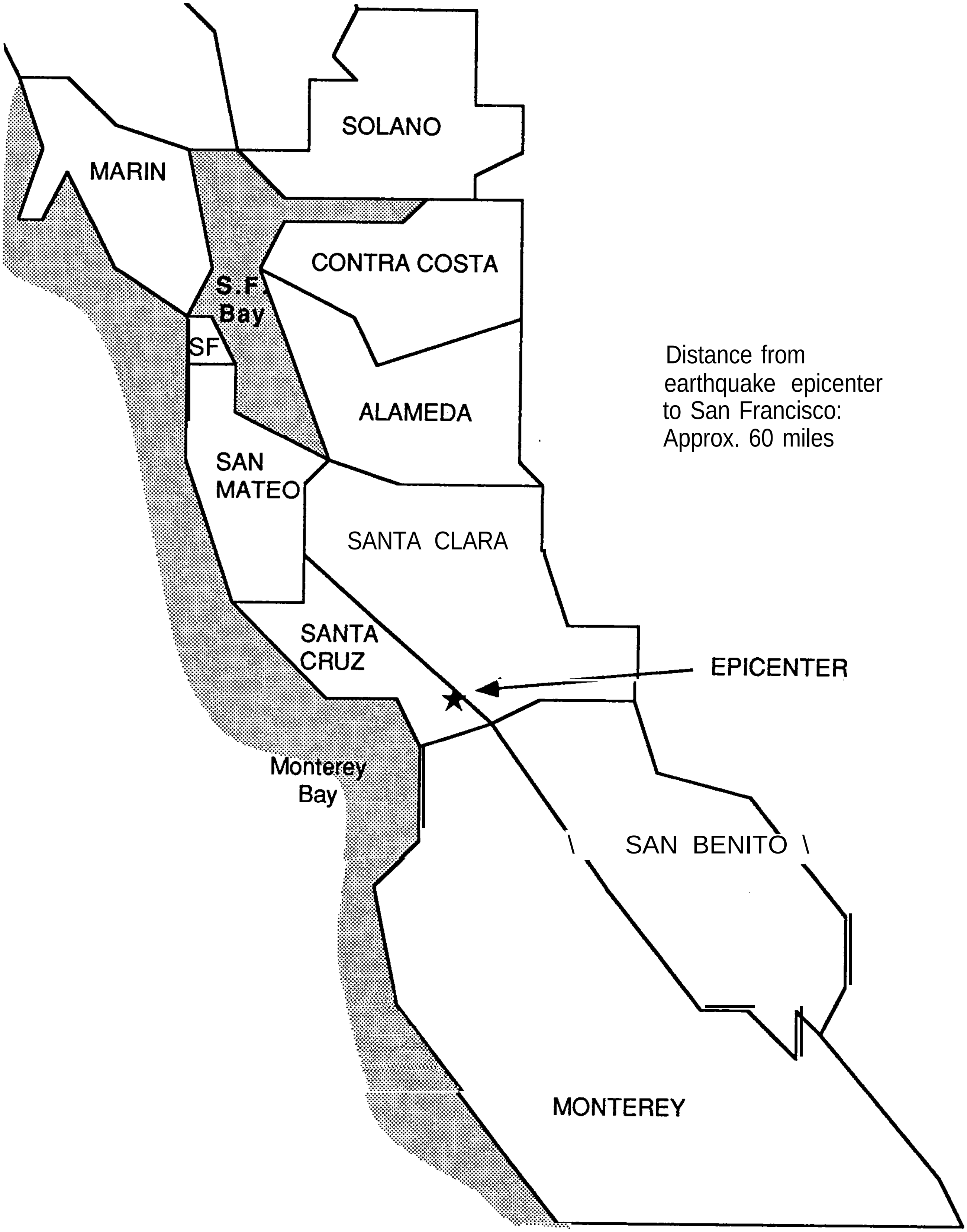


Figure 2.
Location of counties in the disaster declaration area.

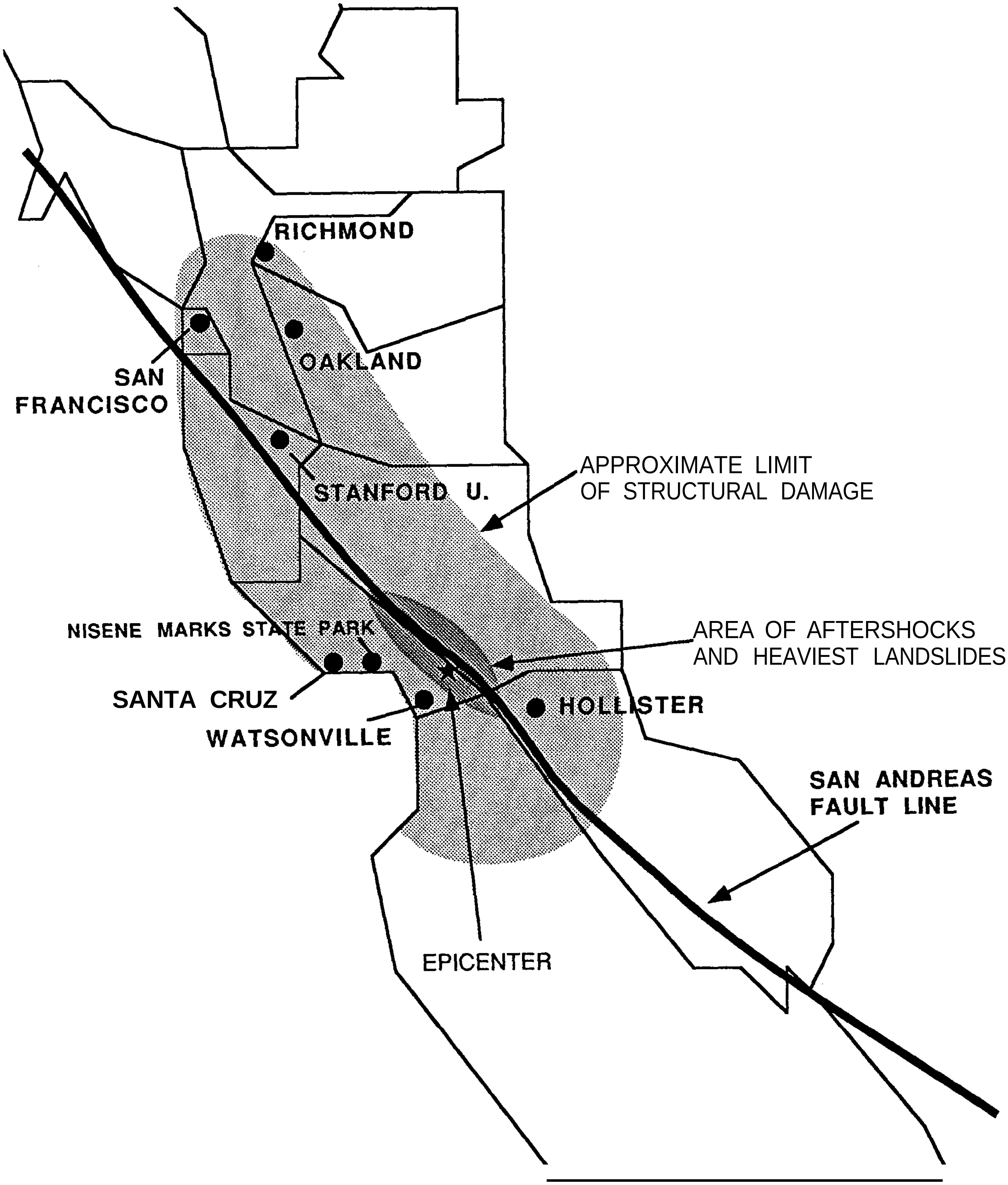


Figure 3.
Location of places mentioned and area of heaviest damage.

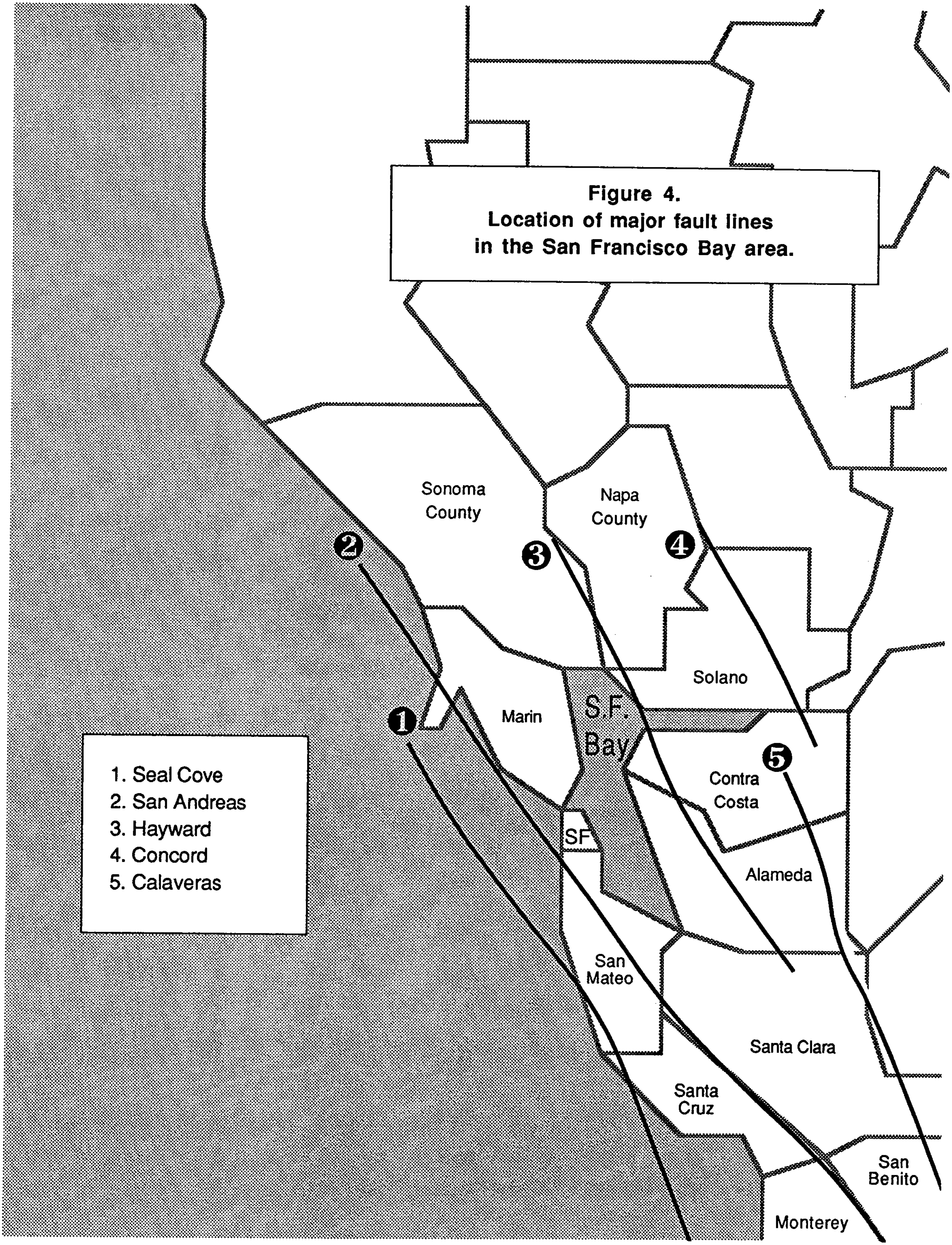


Figure 4.
Location of major fault lines in the San Francisco Bay area.

INTRODUCTION AND ACKNOWLEDGMENTS

Soon after learning of the devastating Loma Prieta earthquake affecting the San Francisco Bay area, a response team that consisted of representatives from the National Fire Protection Association, the California State Fire Marshal's Office, the U.S. Fire Administration, and the International Conference of Building Officials was assembled and dispatched to the area. This seven-member team made on-site visits to those jurisdictions affected by the earthquake in order to assess the state and local emergency management response.

Team members had diversified backgrounds in structural engineering, fire protection engineering, and emergency rescue and response; and members also had extensive work experience in city, county, state, and/or federal government matters. The California State Fire Marshal, James McMullen, graciously made office space and his staff available for the team. Further, the fire marshal provided transportation and made arrangements for team members to visit state and local emergency coordination centers throughout the affected area. The team spent five days observing, assessing, and discussing with state and local emergency response officials various aspects of their operations. This early-on information was invaluable to the team and provided the data for producing an NFPA Alert Bulletin concerning the earthquake. The Bulletin was produced within two weeks of the earthquake and received wide distribution among the fire service and other emergency responders and other organizations concerned about minimizing the effects of earthquakes.

After the initial on-site visit and distribution of early-on technical data to emergency service organizations, the team proposed that follow-up work was necessary to more fully document the emergency management of this disaster. The National Fire Protection Association, with input from the other organizations, developed a proposal for a follow-up study for consideration by the Federal Emergency Management Agency, U.S. Fire Administration; and a grant was awarded September, 1990 to continue this ongoing study. The objective of the grant was to provide a report that would be useful to local governments throughout the U.S. in assessing the adequacy and features of their disaster response plans.

Specifics of the grant required the report to address:

- The use of the incident command system to mitigate fire, structural collapse, and medical emergencies.
- Operation of multi-jurisdictional disaster response plans.
- Policies and procedures for post earthquake structural inspections.
- Needs for procedural improvements that will increase the effectiveness of plans in other disasters.

This report represents the final report of the follow-up study of the Loma Prieta earthquake and fulfills the requirements of the grant.

The NFPA is grateful to have had the opportunity to conduct such a follow-up study and wishes to express its gratitude to the other participating organizations and individuals involved in the study. Specifically, James McMullen; Gary Tokle (formerly with CSFM); Sandra Simpson and Pamela Vawter, California State Fire Marshal's Office; Susan Dowty, International Conference of Building Officials; Gordon Sachs, United States Fire Administration; Thomas Klem (Project Manager) and Mark Conroy of the NFPA staff. These individuals participated in the on-site work and the writing of the Alert Bulletin, and provided input to or wrote sections of the final report. In addition, Jerry Laughlin, Books On Fire, served as Technical Editor. Without the help of these individuals this report would not have been possible.

Also vital to the production of this report were those individuals that served in various capacities that were directly involved in the mitigation of the earthquake or that candidly provided their assessment of this major disaster and/or provided technical review of the final report. These individuals include: Fire Chief Frederick Postel, San Francisco Fire Department; Assistant Chief Andrew Stark, City of Oakland Fire Department; William M. Medigovich, Regional Director, FEMA Region IX; Fire Chief Gary Smith, Watsonville Fire Department; Eileen Baumgardner, Office of Emergency Services; Fire Chief Ed Ekers and Deputy Chief Pat Brown, Santa Cruz Fire Department; J. F. Goodfellow, California Seismic Safety Commission; and Maureen DiTullio, project secretary, for her continued support and assistance during this project.

This report represents a combined effort of these individuals and numerous other individuals who gave of their time and effort so that others might learn from their experiences.

Overview: The Nature of Earthquakes

Each year approximately 6,000 earthquakes are detected throughout the world: 5,500 are either too small or too far from populated centers to be felt directly; 450 are felt but are too small to cause damage; and 35 cause only minor damage. The destruction of property and loss of life from the remaining 15, however, require fire departments and other emergency agencies in earthquake-prone areas to improve their operating ability to deal with such mass disaster. An average of 20,000 people die every year from earthquakes. All 50 states have recorded earthquakes. The next incident could happen anywhere.

Fault lines

Earthquake potential occurs when pressure builds up along certain adjacent massive sections, or plates, of the Earth's surface. The Loma Prieta earthquake was caused by a build-up of pressure where one section was sliding against the other. This sliding movement is relatively slight--only inches per year as an average-but the weight of the affected sections is tremendous. The meeting point of these two adjacent sections is called a fault.

These sections were once apart but, after millions of years of almost imperceptible movement, the sections now squeeze against each other while the movement forces continue to build pressure.

Movement along these faults is not smooth and continuous. The massive weight causes friction loads that temporarily hold back any movement. After a period of time, however, the pressure along the fault increases until it exceeds the friction load. At that time a sudden fracture ruptures along the fault. One section of the Earth's surface briefly slips and releases the built-up pressure until friction once again overcomes the now-diminished movement pressure. The size of the earthquake is determined by the dimensions of this fracture: the larger the fracture, the greater the energy release. Pressure along a fault may take many years to build to a critical point, but its release takes only seconds.

The most significant fault in California is the San Andreas fault extending 800 miles from Mexico to just north of San Francisco. It is well-known because it is highly visible along much of its length, and because it is the scene of relatively high earthquake activity, including the 1906 San Francisco earthquake. California has numerous other faults that are capable of producing damaging earthquakes, including the Hayward, Calaveras, San Gregorgio and Concord faults, all of which extend through the San Francisco Bay area (Figure 4). Equally dangerous faults can be found along the entire length of the San Andreas fault line.

Notable faults also exist outside of California. Three earthquakes on the New Madrid fault along the Mississippi River basin in Missouri during the winter of 1811/1812 are estimated to be the largest ever experienced in the continental United States. And the 1964 Good Friday earthquake in Alaska is the largest recorded modem earthquake in all the United States. The Northeast is currently active seismically in a line from New York City northward into Canada. In South Carolina, Charleston experienced a major earthquake in 1886. The implications for near-future earthquake damage elsewhere in the United States is discussed in the Appendix.

The Richter scale

A common measurement of the strength of an earthquake is the Richter scale, based on the size of the seismic waves radiated by the rupture. The Richter scale results from carefully controlled measurements, but because it is logarithmic-rather than mathematical-it is subject to misunderstanding when severity is considered. On a normal linear scale, a magnitude of 5 would be half as powerful as a magnitude 10, and a 7 would be 10 percent stronger than a magnitude of 6. On the logarithmic scale, each increasing digit represents a value that is ***many*** times the value represented by the lower number. The lack of a simple mathematical relationship leads lay people to misunderstand the extra power of earthquakes with higher magnitude. On the Richter scale, an earthquake of magnitude 8 represents 30 times the energy of one with a magnitude of 7. On this upward-sliding scale, the magnitude 8 is 900 times stronger than a magnitude 6. Furthermore, a magnitude 7.1 is significantly stronger than a magnitude 7.0. In terms of fault slip, an earthquake of magnitude 7 will rupture a fault segment for a few tens of miles, while an 8 magnitude will rupture a fault along a few hundreds of miles.

In this regard, becoming complacent after studying or surviving a 7.1 magnitude is wholly inadequate in view of expectations of scientists for a possible quake in California (or elsewhere) with a magnitude higher than 8.

The Richter scale magnitude alone is not sufficient to evaluate the damage done by an earthquake. Other factors, such as building construction, affect the danger and losses from collapse. For example, the 1988 earthquake in Soviet Armenia registered a magnitude of 6.9 (less than Loma Prieta), yet between 45,000 and 55,000 died, mostly from structural collapse.

When the earth moves

Ground shock waves radiate from the fault rupture and travel more easily along the fault than perpendicular to it. The waves also decrease rapidly as they move away from the epicenter. The worst damage occurs when buildings, other structures and people are in areas vulnerable to movement induced by the seismic waves. This movement has the potential to cause collapse of inadequately strengthened buildings. In the Loma Prieta earthquake, the rupture extended about 25 miles in the first 15 seconds. Seismic waves travel farther and take extra time, but all of this still takes place extremely rapidly. This allows very little time for occupants of homes and other buildings to react and escape after the seismic waves hit.

Collapsed buildings are highly visible but are not the only damage done by the shaking ground. Underground utilities are also subject to serious damage from excess motion of the ground. Water mains in many cities are decades old and made from brittle cast iron. When they break, the trouble may not be immediately apparent. Natural gas pipes suffer the same types of breaks, and the results can be worse. All of these difficulties are exacerbated when electrical and telephone lines are severed, making communications and emergency response more complicated.

A strong building may survive the earthquake but be destroyed by resultant secondary disasters, including landslides and fires. Where buildings are not at risk, landslides may block roads or topple utility lines. Also, buildings are not the only structures at risk; dams and bridges may fail and add to the catastrophe.

When the pressure builds up along a fault line until an earthquake occurs, the rupture is usually followed by a series of aftershocks of diminishing intensity. Analysis of California earthquake sequences in the previous 50 years by the state Office of Emergency Services (OES) suggests that after a magnitude 7 earthquake there is a 20 percent chance of a magnitude 6 or larger aftershock in the first 24 hours following the main event. The chances for another magnitude 7 or larger earthquake on an adjacent segment of the fault following the main event is remote.

Soils

Seismic wave behavior and travel from an earthquake epicenter is affected by the ground they move through. The influence of geotechnical factors on damage patterns was the single most pronounced feature of this event.

The supporting capacity of soil is especially important during an earthquake. Rock movement caused by the radiating seismic waves from a fault slippage is normally diminished over distance when moving away from the epicenter, but under certain conditions movement can be amplified as the force travels upward through deep soil of high-clay content to the ground surface. The bowl shape and the soils of the San Francisco Bay area contributed to this amplification potential. The resulting stronger surface shaking can be more damaging than the motion radiated through rock alone or rock overlain by shallow, less-flexible soil layers.

Coastal areas often have a shallow depth of sandy soils that are saturated by groundwater. When these unpacked, saturated sandy soils are dredged up and used for filling of low tidal areas reclaimed for commercial or residential development, they are subject to liquefaction, defined as the loss of strength and supporting capacity of a saturated soil due to ground shaking. Much of the sandy fill temporarily behaved like quicksand. Uneven settling can cause additional building collapse, even when the building has been designed and constructed to withstand the surface shaking forces.

In the Loma Prieta earthquake, soil liquefaction also contributed to damage to buried utility lines, a runway at the Oakland airport and bridges along two rivers.

The Marina District of San Francisco was largely constructed on saturated, sandy fill. Soft soils were not uncommon in the region. Many of the deaths, except for those at a freeway collapse, and most of the property damage in the Bay area were due to collapse or partial collapse of older structures on poor (soft) ground.

The Loma Prieta earthquake demonstrated a significantly higher level of liquefaction vulnerability than had been generally anticipated by local planners and decision-makers. Similar soft soils are also found on the East Coast and in river cities such as St. Louis and Memphis, both at risk from an earthquake along the New Madrid fault.

Predicting earthquakes

Scientists have been working to improve their ability to predict earthquakes, but precise predictions continue to elude them.

Many fault segments have been identified along the San Andreas fault. Earthquakes tend to recur on these segments at semi-regular intervals, and mapping of these events suggest the segments most likely to slip in the near future. As the time since the last earthquake on a particular segment increases, the chances for the next earthquake increase. According to the U.S. Geological Survey, “If we know the time since the last major earthquake on a given segment, we can determine the probability that the next major event will occur within a specific period of time.”

The Loma Prieta earthquake occurred along one of the six California fault segments identified as most likely to sustain a 6.5 magnitude or larger event in the 30-year interval of 1988 through 2018. Two earthquakes in the region before the mainshock (one only two months earlier) were thought to be possible foreshocks of a major event within five days. California OES issued a public advisory each time, but neither proved to be an actual foreshock to the earthquake that finally occurred. No other recorded activity served to allow short-term prediction of the Loma Prieta earthquake.

The Parkfield segment of the San Andreas fault in Central California now carries a 95-percent probability of a magnitude 6 earthquake before the end of 1993.

Meanwhile, work is underway to improve the resolution and reliability of such forecasts.

The 1906 San Francisco earthquake

Earthquakes in California are usually compared to the 1906 San Francisco earthquake and fire. That earthquake had an estimated magnitude of 8.3. From a population of 340,000 at that time, about 700 people were killed. Approximately 28,000 buildings were destroyed and 200,000 were left homeless.

In 1906, liquefaction and settlement in the unstable sandy soils caused damage to water mains, and water was not available when fires started to spread. Approximately 85 percent of the total damage in the City of San Francisco in 1906 was caused by fire. Afterward the city constructed an auxiliary water supply system to provide for separate emergency fire protection. Divided into two zones, each operates at about 2.5 times the pressure of the regular municipal water supply system. The auxiliary system (the only high-pressure system of its type in the U.S.) was designed to work independently of, but in parallel with, the municipal system. It has no building connections or service lines. Access is only through fire hydrants.

The fire department has since developed a portable water supply system consisting of special hose tenders and large-diameter hose. The components could be moved throughout the city and connected with underground cisterns, underground pipes, a fireboat or other water sources.

Preparations for Earthquake Response

Work on the Southern California Earthquake Response Plan (SCERP) began in the early 1980s and had proceeded to a final draft by 1986. SCERP exercises were conducted in 1985, 1986 and 1987. Application of SCERP to Northern California began in 1988 to specifically address an earthquake in the San Francisco Bay area. The plan was to describe the responsibilities, organizations and concept of operations necessary for a massive emergency response effort by all levels of government on a scale never before undertaken. Described as a living document, the plan was expected to need periodic updating to reflect lessons learned from exercises, improved response capabilities and additional details developed through ongoing planning.

The Plan for Federal Response for a Catastrophic Earthquake was issued in 1987. The plan provides mechanisms for Federal agencies to assist local and state governments to respond rapidly to a major earthquake. Since 1987, state and Federal agencies have worked together to develop supplements to the plan for responding to earthquakes in Northern and Southern California.

Training

The state and Federal plans were first exercised in August 1989, less than three months before the Loma Prieta earthquake. “Response 89” was a Federally sponsored exercise to test the Federal and state response plans. Participation in Response 89 included Federal and state agencies with roles assigned in the state and Federal plans. The specific exercise scenario to be addressed was an earthquake affecting the San Francisco Bay area.

Activities of the exercise occurred in Sacramento (headquarters of OES), at the Federal Emergency Management Agency’s (FEMA) Emergency Information and Coordination Center in Washington, DC, and at numerous other sites in California and elsewhere.

Assumed characteristics of the exercise earthquake included a rupture along the Hayward fault (see map of California and Bay area faults), Richter magnitude of 7.5 and major damage to nine counties. Damage represented was a worst-case scenario for that fault segment of approximately 10,000 deaths, 3 1,000 injuries requiring hospitalization, massive loss of utilities, numerous fires, and unusable airports and bridges.

Worthwhile training resulted from the exercise. Before this opportunity, only 29 percent of Federal participants and 32 percent of state participants had been involved in an earthquake response exercise.

Findings from the review of the exercise indicated that it was a useful planning tool, and additional training would only improve response to a major disaster.

Fire service mutual aid

The threat of earthquakes in California is well known, and emergency agencies have attempted to better prepare for these disasters. Two occurrences in 1970 gave more focus to the need for preparations for major multijurisdictional response.

- The California Emergency Services Act revised disaster preparedness planning in the state and established the legal basis for the governor’s response to major emergency situations faced by the state. The Office of Emergency Services (OES) became the state agency to coordinate response to disasters. OES holds a large supply of fire and rescue equipment.
- A number of challenging wildland fires triggered special interest in planning for handling large-scale disasters. The FIRESCOPE program (Firefighting Resources of California Organized for Potential Emergencies) resulted in the development of an incident command system (KS), which provides an organizational structure for emergency management involving response by diverse agencies. ICS consists of procedures to control personnel, facilities, equipment and communications. Its success comes from its application to a situation even as it grows and becomes a multiagency operation. The

system is designed to use common terminology and operating procedures so that the four command sections (operations, planning, logistics and finance) can be staffed by qualified personnel from any emergency services agency. The system's success grew until it became accepted and implemented beyond wildland fire action. Now this concept is used by fire agencies on a statewide, national and, in some cases, international basis. ICS became a responsibility of the Office of Emergency Services in 1980.

At the time of the Loma Prieta earthquake, a Master Mutual Aid Agreement had long been developed through the cooperation of every segment of California's fire service and signed by the state, all 58 counties and nearly all city governments. Local fire officials maintain active involvement in day-to-day system management and operation. The agreement is based on the California Fire Service and Rescue Emergency Mutual Aid Plan, which is based on both self-help and mutual aid. The plan provides for:

- Systematic mobilization, organization and operation of fire service resources of the state and its political subdivisions in mitigating the effects of disaster.
- Comprehensive and compatible plans for the expedient mobilization and response of available fire service resources on a local, regional and statewide basis.
- Establishment of guidelines for recruiting and training auxiliary personnel to augment regularly organized fire personnel during disaster operations.
- Annual update of fire service inventory of all personnel, apparatus and equipment in California.
- A plan and communication facilities for the interchange and dissemination of fire-related data, directives and information between fire officials of local, state and Federal agencies.
- Coordination and implementation at the state level of government.

The plan also divides the state into six mutual aid regions and outlines the positions of operational area coordinator (usually relating to a county), a regional coordinator and a state coordinator, each responsible for maintaining assigned resource inventories, plan details and coordination of mutual aid.

The complexity, frequency and magnitude of disastrous fire problems in California, especially during floods in 1986 and dangerous wildfire seasons in the 1970s and 1980s, gave OES much opportunity to test and revise state fire mutual aid plans.

The California Fire and Rescue Mutual Aid System is highly organized. Publications describe the history and operation of the system. Among the useful information is a guide for local fire chiefs to use in requesting mutual aid. The guide includes a checklist of the vital information needed to properly process a request, such as where the resources are to report and the local radio frequency to be used by responding resources. Local chiefs requesting aid are reminded to keep the Operational Area Fire Coordinator updated on the progress of the emergency.

The mutual aid system is designed to accommodate progressive mobilization, in which requests are handled by the local jurisdiction and operational area first, then by the regional area until even more resources are needed, and the request moves higher. The hierarchy of progressive mobilization is described as follows.

Mobilization

When determined by the responsible local fire and rescue official that jurisdictional resources are inadequate to cope with the emergency at hand, the following steps should be taken:

1. Activate the local mutual aid plan.
2. Notify the Operational Area Fire and Rescue Coordinator.
3. Prepare to receive and utilize mutual aid requested/provided.
4. When jurisdictional and local mutual aid resources are determined inadequate, request needed resources according to Operational Area Mutual Aid Plan.

The **Operational Area Fire and Rescue Coordinator** will:

1. Evaluate resource availability within the operational area.
2. Coordinate the dispatch of requested resources from those available within the operational area.
3. Notify the Regional Fire and Rescue Coordinator and report known situation and resource status of the area.
4. Request mutual aid resources from the regional coordinator to fulfill request initiated by local jurisdiction or to reinforce seriously depleted resources within the operational area.

The **Regional Fire and Rescue Coordinator** will, upon notification:

1. Evaluate conditions and resource availability within the region.
2. Coordinate the dispatch of requested resources from within the region according to the adopted plan.
3. Notify the State Fire and Rescue Coordinator, reporting known situation and resource status of the region.
4. Request mutual aid resources necessary from the state coordinator to fulfill request(s) initiated by the stricken jurisdiction or to reinforce seriously depleted resources within the region.

The **State Fire and Rescue Coordinator** will, upon notification:

1. Evaluate conditions and resource availability throughout the state.
2. Alert all other Regional Fire and Rescue Coordinators of anticipated inter-regional dispatch of fire service resources.
3. Select region(s) from which resources are to be mobilized to fulfill requests.

4. Coordinate the response of inter-regional mutual aid resources. Inter-regional fire and rescue mutual aid resources will be mobilized in strike team configuration.
5. Activate OES and other state agency support personnel, apparatus and equipment necessary to fulfill requests statewide.

GENERAL RESPONSETOTHE LOMA PRIETA EARTHQUAKE

Command and control

When the number of agencies involved in a disaster response increases, the challenges of command and control likewise increase. When a major earthquake strikes, it is certain that a large number of agencies are going to be involved. Questions of authority and organization across jurisdictions must be completely resolved before the incident. This earthquake was followed by confusion in some areas and well-organized response in other areas.

In the first hour after the Loma Prieta earthquake most jurisdictions in the damage zone responded to at least one major incident that had the potential to seriously deplete available emergency resources. In the beginning, in terms of emergency response, this event was a series of local disasters. Before local governments could provide information to others or even request aid from others, they had to assess their own situation and mobilize local resources.

Local response

Operational priorities varied according to local conditions, but usually included:

- ***Getting apparatus out of fire stations.*** Each fire department knew that emergency calls would be following the earthquake; getting the apparatus clear of possible additional collapse from aftershocks was something that could be done to get ready. Although most fire service facilities meet the standards of the Essential Services Buildings Seismic Activity Act of 1986, a number of older fire stations were constructed of unreinforced masonry or non-ductile concrete frames, both having poor resistance to the shaking effects of an earthquake. Damage varied from none to major and included wall and ceiling cracks, buckling of concrete slabs, and collapsed chimneys and/or hose towers. Two fire stations were reported collapsed, either from the initial shock or from aftershocks. Even where damage was slight, apparatus was deemed safer located outside the stations.

- Damage ***assessment.*** When units were not responding to immediate calls for assistance, they often began touring their areas to get an overview of the extent of damage to buildings and to determine if other emergencies existed that had not yet been reported in the confusion after the earthquake.

- ***Utility shutoffs.*** Part of the overload to telephone systems and equipment response included calls from citizens reporting gas leaks and requesting utility shutoffs. These situations often did not require exclusive fire department attention, but the quantity of calls received did affect operational priorities. In the first 24 hours in San Francisco, natural gas leaks accounted for almost 90 percent of the "hazardous calls" category, dropping to no less than 50 percent through the fourth day.

- Rescue. A wide range of emergency response falls under the heading of rescue. Ordinary rescue included the rendering of aid for anyone injured during the quake, and the carrying out of light search and rescue involving individuals trapped in either collapsed wood-frame or unreinforced masonry buildings.

- ***Urban heavy rescue from structural collapse. Three*** sites tasked fire personnel to mitigate situations far from those presented by normal rescue response. A series of serious building collapses occurred at the Pacific Garden Mall in Santa Cruz. A 1.5-mile section of Interstate 880 at Cypress Street in Oakland collapsed onto numerous vehicles. Many structures built on unstable fill in the Marina District of San Francisco collapsed.

- ***Fires.*** A spectacular tire occurred in the Marina District, but major fires resulting from the earthquake were surprisingly few and quickly controlled. A number of smaller fires occurred during restoration of utility service, due to the presence of undetected natural gas leaks.

- ***Emergency medical services.*** EMS calls were numerous and varied after the quake. Some were directly associated with injuries from the quake, but in many others represented a secondary effect in which, for example, an existing medical problem was aggravated by the stress and psychological trauma of the event.

Fire departments varied in their ability to respond to the full range of emergencies facing them. Whether a department had the resources to handle all situations, needed mutual aid or could offer assistance to other departments depended on several conditions, including department size and distance from the epicenter of the earthquake.

In the first four hours after the quake, the San Francisco Fire Department responded to more than 400 incidents (normal average for a 24-hour period was about 160 calls). With off-duty personnel returning to their stations, San Francisco was able to mount a sizable force, but the number of emergencies it faced made it difficult to be able to offer mutual aid resources to other departments.

The Alameda Fire Department, with 25 on-duty members at the time of the quake, operated five engines and two trucks, plus two ambulances. In the first four hours, this department received approximately 150 calls for help. Fortunately, an additional 33 off-duty personnel reported to duty without being called (phone lines were unusable due to overloading).

The Santa Cruz Fire Department consists of three fire stations and a total of 45 career and 22 reserve fire fighters. When the earthquake hit, 12 fire fighters were on duty. With personnel returning to duty, the department responded to 71 calls in the first 15 hours, in addition to the multiple building collapse incidents at the mall on Pacific Avenue. Communications had to be handled from the Emergency Operations Center because the volume of calls overloaded the county communications center.

The Watsonville Fire Department consists of two fire stations and a full complement of 29 career and 30 reserve fire fighters. A total of eight fire fighters were on duty when the quake hit. With personnel returning to duty from home, the department handled 175 calls in the first 16 hours. Regular and emergency power to the emergency operations center was lost, and the Watsonville communications center could not function until the fire chief established a command center in the city hall parking lot.

State response

The overwhelming volume of the immediate requests for emergency services led governments to implement their disaster response plans soon after the earthquake hit. At the state level, the state Office of Emergency Services immediately activated the Region 2 Emergency Operations Center in Pleasant Hill and the State Operations Center in Sacramento at 5:30 p.m. to coordinate and manage state response efforts.

The State Operations Center was able to start up quickly in part because it was during the work week and the time of day found most personnel still at their desks. The earthquake was felt in Sacramento, giving an early signal to others who needed to respond to the Center. Early situation reports indicated significant scattered damage but no outright regional devastation. For this reason, normal emergency operating procedures were used rather than the recently completed and tested Draft Plan for a Catastrophic Earthquake in the San Francisco Bay Region.

Tasks at the State Operations Center during an emergency included gathering information, creating and updating situation reports, briefing state officials and the media, processing requests for resources and initiating the recovery process. OES Fire Division set up its operations center for more detailed evaluation and tracking of fire mutual aid requests.

Initial reports following the earthquake clearly indicated that facilities under the prime jurisdiction of the California State Fire Marshal (CSFM) had been damaged. Steps were taken to assess that damage. Of initial concern was the condition of health care facilities, public schools and state-owned buildings. These activities are covered in the section on Recovery.

Simultaneously CSFM staff responded to the state Office of Emergency Services operations centers in Sacramento and Pleasant Hill (in Region II) to assist in coordinating fire service emergency response.

Mutual aid response

The California Fire Service and Rescue Emergency Mutual Aid System dispatched 112 fire fighting resources, including 17 engine strike teams (each team consisting of five engines and a strike team leader), 3 OES heavy rescue/fire units, 3 OES mobile support units, 3 local government rescue units, 1 lighting unit and 1 major incident management team and a resource management component from the California Department of Forestry and Fire Protection.

Within the Alameda County operational area an additional 15 engines and trucks were provided through the area mutual aid plan before moving to the state-level resources.

Regarding requests for assistance, an assumption was made at the State Operations Center that local jurisdictions would make contact if and when mutual aid resources were needed. Similarly, the State Operations Center assumed that an absence of requests meant a particular jurisdiction did not need state assistance. This was not always true. Fire department chiefs in some towns with the greatest damage, coupled with impaired communications systems (Watsonville was one example), assumed that every other department was equally struggling to cope with its local situation and would be unable to offer mutual aid assistance. After making that assumption, some of these departments delayed seeking the assistance that would have been helpful.

Federal response

During the first evening after the earthquake, the Federal Emergency Management Agency (FEMA) convened a meeting of the multiagency Catastrophic Disaster Response Group (CDRG) in Washington, DC. Along with FEMA, representatives from California and from numerous Federal agencies attended and discussed the requirements for Federal assistance to supplement the initial local and state efforts.

The CDRG placed a conference call to the state Office of Emergency Services in Sacramento. State officials indicated that they were still assessing the damage and so far had been able to meet the needs for assistance from the state and local governments.

During the first evening the California lieutenant governor declared a state emergency (the governor was out of the country on business). On the next morning he asked FEMA for a major disaster declaration under Public Law 93-288, the Disaster Relief and Emergency Assistance Act. President Bush made the declaration that day, less than 24 hours after the earthquake, specifying the City and County of San Francisco and the counties of Alameda, Monterey, San Benito, San Mateo, Santa Clara and Santa Cruz. Subsequently, Contra Costa, Marin and Solano Counties were also declared a part of the disaster area.

At the time of the Federal declaration, the entire scope of the disaster was still not known, so FEMA initiated a "limited activation" of its ***Plan for Federal Response to a Catastrophic Earthquake.*** Federal agencies with responsibilities under the plan made preparations for possible response activities. Under a limited activation of the plan, FEMA channels mission assignments to Federal agencies at the request of the state emergency office. For the most part, California determined that it could handle the emergency with the state and local resources already available.

A military plane flew over some of the affected areas near Fort Ord, and the Pentagon confirmed that state and local agencies seemed to be responding adequately. The Federal agencies coordinated by FEMA remained on alert, but the earthquake emergency response did not exceed or deplete the available local and state resources. Consequently, FEMA was more involved in the longer-term recovery process than the short-term response effort.

FEMA opened a toll-free informational hotline on October 19 to answer questions from the public. Hundreds of lines were accessible by calling a single toll-free number routed out to Texas, where it avoided placing extra demand on the local lines. Spanish-speaking operators were also available.

Destruction from the Loma Prieta Earthquake

Building damage and collapse

Structural damage typically was limited to unreinforced masonry commercial buildings, older wood-frame homes and apartments, mobile homes, and nonductile concrete frame structures. The number of structures destroyed or damaged (the majority were damaged to some degree rather than completely destroyed) was staggering:

- More than 22,000 residential structures
- 1,567 commercial buildings
- 137 public buildings

Buildings suffered total or partial collapse from the initial shock and from aftershocks. The nature of these collapses was related to the distance from the epicenter, the type of soil underneath, construction materials and the application of modem engineering and codes.

The State of California uses the Uniform Building Code, and structures built in accordance with the latest edition of this code typically were not significantly damaged. Other newer structures also generally suffered little, especially where built on firm ground. Building damage occurred most often to structures with recognized vulnerabilities and to those built on soft-soil deposits.

Wood-frame buildings on poor soil: The Marina District of San Francisco suffered some of the worst building collapse and fire damage in San Francisco. Much of the Marina District consists of landfill placed starting a hundred years ago to reclaim marshes and to fill a small baylet. Silty and uncompacted sands were used. They remained loose and saturated by the high water table. Additional filling occurred when the Marina District was selected as the site of a 1915 exposition and world's fair. More fine sand produced more loose, saturated fill. These conditions are vulnerable to potential soil liquefaction during earthquake shaking. The result is that underground utilities were broken from the ground shaking, and uneven settlement contributed to building collapse.

Most structures in the Marina District are wood-frame, two to five stories high and originating in the 1920s. They were built on uncompacted sandy fill. Most were constructed with a parking garage as the first story. This type of building is described as "soft story," meaning that the wide doorways for vehicles and lack of support in the open garage reduced the building's resistance to twisting and shear forces from an earthquake. Comer buildings suffered more collapse because they lacked the additional support of adjacent walls on the open sides.

Unreinforced masonry structures: The most concentrated and severe damage to buildings occurred in unreinforced masonry bearing-wall structures. Failures resulted from inadequate anchorage of the walls to the roof and floors, complicated by the limited strength of the materials and poor workmanship. Over time, the mortar and wood framing can deteriorate and contribute to poor performance in an earthquake. Unreinforced chimneys caused widespread damage to structures that did not collapse.

The hazards of this type of construction during earthquakes has long been known. Many of these buildings were built before modem codes were written, and retrofitting is expensive. The result during the Loma Prieta earthquake: eight people were killed by falling masonry; and more than 860 unreinforced masonry buildings were damaged, causing major economic and social disruptions in Watsonville, Santa Cruz, Los Gatos and Hollister. In San Francisco, 29 inspected buildings of this type were severely damaged and considered unsafe.

The Pacific Garden Mall (Pacific Avenue) in Santa Cruz is an area of older buildings that had recently been attractively and expensively rehabilitated. Improvements to the buildings did not include significant strengthening for earthquake survival, and much of the mall suffered irreparable damage. Two fatalities occurred from these collapses.

Life-threatening unreinforced masonry collapses also occurred elsewhere in Santa Cruz, in Hollister, Los Gatos, Oakland and the San Francisco financial district.

Reinforced concrete frame structures: Many highway overpasses use this construction, but it is also used in buildings such as warehouses, hospitals and schools. It is commonly used for moderate heights of four to eight stories, but some are as high as 20 stories. Concrete columns and beams are reinforced with steel bars placed lengthwise. Unfortunately, most structures of this type built before the mid-1970s do not have adequate reinforcement. The nonductile concrete frames are not designed to withstand the repeated bending they get during an earthquake. Some of these structures built in the 1950s and 1960s had added flexibility to absorb lateral seismic forces, but too much drift also causes collapse or allows the building to pound against an adjacent structure.. .to the detriment of both.

Buildings near the epicenter: Buildings of all types were at greater danger of collapse where they were closer to the epicenter of the earthquake. Older residential buildings near the epicenter suffered widespread damage, while newer homes had a higher resistance to damage. Chimney damage was noted in as many as 40 percent of the older homes in Watsonville. Unbraced walls and unanchored sills accounted for much of the severe structural damage, mainly to pre-1940 homes. In many cases these homes moved laterally up to a foot, until the cripple wall became unstable and collapsed. Similar homes in Santa Cruz suffered damage more often where on poor soils.

Engineered structures: These structures generally fared well. Most of the visible building damage resulting from the Loma Prieta earthquake was suffered by structures built before the building codes required special provisions in seismic zones.

Modern high-rise buildings: Modem steel-framed buildings performed commendably in this earthquake. These buildings allow flexibility during a quake, but non-structural damage may be sustained during swaying through large displacements.

The number of total collapses was relatively low, but the total damage figure is very high. There was no complete collapse at Stanford University, yet damage on the campus was approximately $160,000,000 when structural and content damage is considered. Most of the affected buildings were built before seismic codes were adopted.

Poor workmanship can overcome the protection of special strengthening to resist an earthquake. A six-story San Francisco building had been seismically strengthened with steel braces, but the attachment of the braces was inadequate and most of the bolts failed.

Collapsed buildings overwhelmed some jurisdictions. Watsonville, with its two fire stations, had to cope with the collapse or shifting off the foundation of 200 residential structures and 14 major commercial buildings.

Elevated freeway collapse

Elevated freeways constructed of reinforced concrete fared poorly in the affected areas. A dramatic failure occurred in the double-decked section of Interstate 880 along Cypress Street in Oakland. Major damage also closed Interstate 280 in San Francisco and Interstate 480, the Embarcadero Freeway. Other failures cut off Interstate 80 at the San Francisco-Oakland Bay Bridge, where a partial collapse of one span lead to two fatalities; Interstate 980 in Oakland; and State Highway 17 in Santa Clara County. Each one forced long-lasting detours that hampered immediate emergency efforts as well as subsequent commuting by residents and workers. Damage to the San Francisco-Oakland Bay Bridge involved relatively small segments of the structure, but that vital transportation link remained closed for a full month.

Few people in the United States were not aware of the Cypress Street situation, where the upper deck collapsed onto rush-hour traffic. The Cypress Viaduct was California's first continuous double-deck freeway; it became a main artery to and from the Bay Bridge and a number of Bay Area communities. A four-lane southbound roadway was directly above the four-lane northbound roadway. The structure was completed in 1950 when the use of prestressed concrete in bridges was new in this country and less was known about seismic effects on this construction. Although the area was more than 50 miles from the epicenter, underground conditions in the Bay basin contributed toward local amplification, in which ground movement from an earthquake increased in relation to other different geographical areas equally distant from the epicenter.

According to a 1987 count, the best estimate of normal freeway traffic volume for a typical Tuesday in October at 5:00 p.m. would be 1509 vehicles per hour in each of the four lanes southbound and 1400 per hour in each lane northbound. Cypress Street runs adjacent to the freeway.

The first report to the Oakland Fire Department about the Cypress Street collapse came in six minutes after the quake hit, and by that time almost all of the fire units in northern and western Oakland were out on earthquake-related calls. Fortunately Oakland's fire dispatch center could still receive calls after the quake, but initially only two civilian dispatch operators and a supervisor were on duty. An available response was sent to Cypress Street to investigate.

Even before the Cypress Street report, as more and more companies were dispatched, the volume of telephone calls for assistance, department radio traffic and the sound of the associated data system for unit status tracking added to the dispatch overload. During the first 30 minutes, all department communications would have to be funnelled to the radio because of damage to the land phone cable connecting the fire stations. Fire companies were assigned to incidents and dispatched before the information could be entered into the computer-aided dispatch system. The result was that the computer could no longer indicate which companies were available for service.

Early contacts from the Cypress Street scene reported "total collapse as far as the eye can see." Initial estimates, based on normal rush-hour patterns, suggested a potential loss of life as high as 300. Fortunately, normal rush-hour traffic was not present, probably because of the number of people commuting early that day to see two local teams in the third game of the World Series, beginning at 5:30 p.m. and to be televised from nearby Candlestick Park.

The collapse extended from 18th to 34th Streets. Coordination of the rescue effort was complicated by this 1.5-mile length, the instability of the damaged viaduct, and the inability to quickly assess the number of people trapped. Even people in vehicles on the top section of the freeway had been injured from the fall. The rescues from under the collapsed top section were especially difficult; in one case a man was fmally freed from the wreckage 90 hours after the earthquake hit.

Hundreds of citizen volunteers performed some of the first rescues using makeshift ladders, ropes and trees along the viaduct. Cypress Street is adjacent to an industrial area, so heavier equipment items, such as forklifts and cranes, were also available. Volunteers continued to augment arriving fire and medical units as three response divisions were established to control the scene and the rescues.

Medical response was hampered by the county medical central dispatch frequency being out of service. All medical communications had to be handled through the different ambulance services on each of their separate frequencies, by telephone, by runners, or any combination. At one point a helicopter attempted to land on the upper deck, called by unknown persons for removal of victims. Due to the instability of the structure, the helicopter was waved off.

Any rescues to be made from the lower deck would be from cavities of confined open space between the sections of collapsed upper deck. Rescuers had to crawl into these areas and hope that the rest of the structure did not collapse. According to a California Highway Patrol officer on the scene from the beginning, one particular section of the collapsed upper deck had settled 1.5 inches in the first 20 minutes. Aftershocks, vehicle fires, darkness, the number of untrained volunteers along the collapse area, and the disruption of roaming press crews caused the command staff to clear the area in order to provide more control for authorized rescue teams. Each division was then supported by a structural engineer, a medical crew and a safety officer.

Numerous mutual aid units arrived through the night. The quick response of the mutual aid system was indispensable in providing the resources needed to meet all aspects of the emergency.

Managing the emergency scene at the Cypress Street freeway collapse in Oakland was especially difficult due to the extensive area of the collapse, the weight of the collapsed sections pinning many victims, and the length of time that the operation continued. Rain and colder weather on the second day increased the difficulties, although by 3:00 a.m. all living victims except one had been removed. In those first 10 hours rescuers and medical personnel triaged, treated and transported 116 people to 15 hospitals.

Every activity required extra effort A truck company was alerted to a car in the collapsed area where two children were trapped with their dead mother, but the officer in charge could not bring the truck into service until a volunteer forklift operator cleared the piles of concrete freeway rubble. One child was freed in two hours. After five hours of effort, a team of doctors decided that the only way to free the boy was to perform an on-scene amputation. In one case a man was trapped in a car flattened to no more than two feet high in some places, and spilled gasoline was nearby. A fire crew brought up a hoseline and hydraulic power tools and jacks-but the only tools that could be used in the confined space was a hacksaw blade and other tools of similar size. Rescue efforts were also hampered by burning vehicles under the collapsed sections of the freeway that were cut off from normal extinguishment procedures.

More than 200 fire fighters worked at the Cypress Viaduct collapse during the first night of operations. After 36 hours of extensive multiagency operations at the scene, Oakland requested additional equipment and mutual aid command assistance from the state Office of Emergency Services (OES). OES in turn asked the California Department of Forestry and Fire Protection (CDFFP) to supply a major incident management team to assist. CDFFP sent about 70 personnel to support Oakland Fire Department's activities through coordination of the planning, logistics and finance activities.

The lengthy body removal phase was difficult and tedious, with each removal taking from three to four hours to complete because of the weight of the collapsed material. This phase continued around the clock for the week that followed, until all recoverable remains were removed. Eight bodies could not be recovered until the structure was brought down during demolition.

Demobilization of the Cypress operation began in the evening of Sunday, October 22, five days after the earthquake.

Fires

The number of fires was relatively low considering the potential from any earthquake. Less than 100 were directly attributed, and all were brought under control within a few hours.

The Marina fire. San Francisco had 27 structural fires during the first seven hours. The largest fire started by the earthquake was in the densely built Marina District. It began in a four-story wood-frame comer building on Divisadero Street. Built in the 1920s, the building contained 21 apartments and a ground floor parking garage. The two lower floors collapsed in the earthquake; the top floors leaned out for several feet.

Fire began in the rear from an unknown cause, but the alarm was delayed in the initial confusion after the collapse. The first San Francisco Fire Department unit arrived at approximately 5:45 p.m., some 40 minutes after the earthquake. It had originally responded to the location of another building collapse, until the crew saw the smoke on Divisadero and went to investigate.

Wind speed was fortunately zero. The first engine connected to a high pressure hydrant (part of the auxiliary water system specially designed for fire fighting) directly in front of the building but found no water pressure.

Shortly afterward an explosion shook the building. Flames shot 100 feet into the air and the building wall fell onto the hydrant. To save the engine, its crew drove it away immediately, ripping the hose from the hydrant coupling. This engine repositioned across the street and continued to operate on the fire.

Numerous exposed buildings also ignited, but water had been found and relayed both from a more distant hydrant and from a lagoon at the Palace of Fine Arts. An attempt by a pumper to draft from the Marina lagoon was unsuccessful due to low tide.

Several more explosions occurred. The affected buildings collapsed and destroyed a number of hose sections. The entire neighborhood was threatened.

Additional water was available from the San Francisco Bay at the Marina waterfront only two blocks away. Fire ground commanders called for the fireboat ***Phoenix*** and the portable water supply hose tenders. The fireboat and three hose tenders arrived at 6:00 and crews set up four major runs (a total of 6,000 feet) of 5-inch hose between the fire and the fireboat, using nine portable hydrants.

At least 10 engines were operating on the fire. Water from the fireboat had a positive effect, and this fire was under control at about 8:00 p.m. Before all fire operations were concluded in the Marina the fireboat pumped 6,000 gpm for more than 18 hours.

Beyond San Francisco, Berkeley had a major fire that required the response of the entire department. The fire, involving an auto-service building, started from the ignition of spilled solvents.

Although other areas had a variety of difficulties, fire was a relatively minor one. Santa Cruz County, closer to the epicenter, reported more than 20 fires. The City of Santa Cruz lost only one residential structure, which was fully involved on fire department arrival due to a gas main leak. Watsonville reported that fires destroyed one single-family dwelling and two mobile homes. As in other areas, Watsonville experienced difficulty due to broken water mains. In Santa Clara County a ruptured propane tank ignited a residence fire. The water distribution system for the community had been destroyed, so water was drafted from the community swimming pool.

One wildfire at Nisene Marks State Park in Santa Cruz started from the earthquake. The California Department of Forestry and Fire Protection responded with a major commitment of engines, crews and aircraft, holding the fire to 50 acres.

Loss of water supplies

Conditions in the regular municipal water supply system of San Francisco showed the effects of ground movement in the Marina District. There were 123 breaks, more than three times the number of breaks in the entire municipal water supply system outside the Marina District. This system provides water from 18 different reservoirs and some smaller storage tanks at different levels.

The number and location of breaks in the auxiliary water supply system in the Marina District were unknown immediately after the earthquake. Due to this uncertainty, valves connecting the two zones were not opened and pump stations were not immediately placed in service.

In fact there was only limited breakage in the auxiliary system in the Marina. The most serious damage was from a break in a 12-inch high-pressure cast-iron main. Water flow here and through broken hydrants emptied the Jones Street Tank of its entire storage of 750,000 gallons in about 20 to 30 minutes. When this supply emptied, the entire lower zone of the auxiliary system lost water and pressure. For a period of several hours the lower zone of the auxiliary water supply system had no pressure. To avoid a damaging water hammer effect, the pump stations had to slowly rebuild pressure to allow entrapped air to be exhausted.

Loss of pressure was especially troublesome in the Marina, where damage in the municipal water supply system had cut off alternative sources of pipeline water. The Marina had only a single gate valve. It was designed to be operated remotely with an electric switch, but concurrent loss of electrical power prevented remote closing of this valve.

Outside of San Francisco, water supplies were also interrupted on a wide scale. More than 100 water mains broke in Hollister, and more than 60 broke in the City of Santa Cruz. Loss of electrical power knocked out pumping stations in Santa Cruz, Watsonville, Hollister and Pajaro. Systems were physically damaged, in addition to the loss of power, in communities of the Santa Cruz Mountains.

Hollister, which had 400 damaged residences, lost water for two days. This made water for fire fighting critical. The only remaining water supply for fire fighting was stored in a tank near the emergency operations center. When water mains broke and people began stocking up for their own emergency use, all other water storage was depleted within three hours after the quake. Mutual aid water tenders soon arrived.

Loss of utilities and communications

Electricity: Initially, more than 1.4 million electrical customers lost power in the region.

Sections of Watsonville were without power for four to five days. Power was restored to all but the most heavily damaged areas in the region within a day or two, but for emergency agencies the first few hours are especially critical. Restoring power was hampered and delayed by the danger of igniting natural gas from broken or leaking gas lines.

The loss of electricity in the financial district and in the Marina area of San Francisco, where a fire was out of control, complicated all other emergency responses. Inoperative traffic lights in any densely populated area can contribute to gridlock and hamper emergency vehicle response. Traffic problems from inoperative signals added hours of delay to some off-duty fire fighters attempting to return to duty. Additional requests for emergency assistance came when elevators stalled between floors. Fire crews were completely committed to the existing fire and rescue situations, so Bureau of Fire Prevention inspectors responded to elevator rescue calls in their automobiles.

Telephone: The telephone communications system survived the earthquake without damage to major cable facilities, but network overloading occurred due to the number of calls attempted. The earthquake area is serviced by two area codes. Long distance companies were asked to block incoming calls from another area code to ensure that emergency calls within one zone of the disaster area could get through. While many telephone systems were technically operational, long delays were sometimes experienced in getting a dial tone.

The loss of electrical power caused other problems for telephone systems. Battery backups allow several hours of operation, but rechargers could not immediately be used. A greater problem was the lack of emergency power for some private branch exchanges (PBX), privately owned telephone systems used within larger buildings or organizations and connected to public systems. In the absence of backup power, most of these phones were out of order in the beginning. Many people in these buildings then assumed that the entire public phone system was out of order, although a nearby street pay phone may have been operational.

AT&T reported that it could not immediately staff its switch center in Oakland due to structural damage to the older building. Operational personnel had to wait for an inspection by structural engineers. ITT reported that its switch in downtown San Francisco was down after the earthquake due to loss of power. A battery backup system proved ineffective. The switch was restored the next morning after the quake.

Overall, telephone systems performed better than expected where proper precautions were taken and emergency generators were available.

Natural gas: Broken natural gas lines and valves resulted in leaks throughout the affected area. Some fires followed the leaks. Gas leaks were controlled by main shut-off of systems until building-to-building inspections were conducted to locate and repair leaks.

More than 150,000 customers were without gas in the early hours of the incident and eventually needed to wait for inspection and relighting of their pilot lights. Many residents whose homes had suffered no damage unnecessarily shut off their gas supply, in part due to erroneous media information.

Landslides

The earthquake triggered more than 500 landslides in the Santa Cruz Mountains and along the coast. The net effect was to make many of the roads impassable immediately after the earthquake. Traffic on Highway 17, a major artery between Santa Cruz and San Jose, was severely restricted for almost two weeks due to landslides. Complete repair of the landslides along Highway 17 required 33 days and an expenditure of about $1,800,000.

Longer-term damage may result from the reactivation of pre-existing deep-seated landslides near the epicenter. Reactivation means that future slides are more likely, from unrelated activity such as heavy rains, now that the area has been made unstable.

As many as 800 to 1,000 dwellings housing about 3,800 people were affected by direct or indirect landslide movement in the epicenter region. The severity of the sliding would have been much greater had the earthquake occurred during a wet winter.

Landslides along coastal bluffs had a different character. These bluffs had been eroded by wave action from the ocean and presented steeper slopes than accompanying slides in the mountains. When a landslide began on a steep slope, the impact was often much stronger. Several major rockfalls occurred, one of which killed one person on a beach near Santa Cruz.

Additionally, newly opened tension cracks have been reported on these coastal bluffs and increase the likelihood of more slides during subsequent rains. The largest failure of coastal bluffs occurred 55 miles from the epicenter.

The extent of the deep sliding during this earthquake is a clear indication of the potential future hazard, given the seismicity of the region.

Hazardous materials spills

Two petrochemical plants suffered notable damage. Both were in Richmond (Contra Costa County), 60 miles from the quake epicenter, and both were constructed on sandy fill adjacent to the bay.

Six unanchored storage tanks each with a capacity of 400,000 to 1,000,000 gallons at the Unocal terminal began leaking. Three tanks discharged an estimated 4,800 barrels of gasoline, and one tank lost almost 20,000 gallons of lubricating oil. A berm around the tanks helped contain the spills until the product could be pumped to other tanks. No product entered the nearby San Francisco Bay.

At the Texaco facility, an 800,000-gallon tank began leaking at the bottom plate. This was the only full tank at the facility. Partially filled tanks were not damaged.

These incidents (and other potential hazardous materials spills) could have had some of the longest-lasting harmful effects on the entire San Francisco Bay area, but in the end they received relatively little attention-mainly because the fire department and plant management handled the incident successfully.

Deputies from the California State Fire Marshal Office contacted the six pipeline operators in the Bay area to check on damage to hazardous liquid pipelines. All pipelines were shut down and then allowed a slow start-up after inspection and testing.

Less-dramatic but troubling spills occurred in numerous locations. Stanford University suffered damage from spilled laboratory chemicals. Watsonville Fire Department reported numerous ammonia refrigeration leaks. In one incident, 10,000 pounds of anhydrous ammonia was released in a cold room. Fortunately it was easily contained until cleanup operations could begin.

Aftershocks

An earthquake of this size typically will be followed by many thousands of smaller aftershocks in the following weeks, generally becoming less frequent over time. The danger is that any one could cause additional damage, especially to buildings already weakened by the bigger shocks, and injuries to people.

Within three weeks after the Loma Prieta earthquake, the U.S. Geological Survey had recorded 4,760 aftershocks. The largest was magnitude 5.9, occurring 2 1/2 minutes after the main shock. The second largest, magnitude 5.2, occurred 37 minutes after the main shock. Both of these caused additional damage. A magnitude 5.2 aftershock also occurred on October 18. Another 85 aftershocks were between 3 and 5 magnitude, with 20 of those described as strong. Most of the aftershocks were less than a magnitude of 3; they were recorded by instruments but did not cause additional damage.

Injuries to personnel

Only seven departments reported instances of injuries to fire service personnel. All injuries, except one, occurred during response activities. Only one was serious. The majority of injuries were twisted ankles and knees, often caused when walking in loose, angular debris that is characteristic after an earthquake, especially around collapsed unreinforced masonry construction. Also, falling and shifting debris caused two injuries, an injured hand and smashed fingers. One strained back occurred from lifting debris. One wrist tendon was cut by debris and resulted in eight months' time off duty.

The most dramatic injury to emergency personnel occurred to an off-duty fire fighter who was crushed and trapped in his personal vehicle at the collapse of the Cypress Street Freeway. He was rescued five hours later and spent nine months off duty recuperating from his injuries.

The overall safety record was admirable and according to the Fire and Rescue Division of the Governor' s Office of Emergency Services was due to increased emphasis on fire fighter safety in recent years by fire chiefs, training officers and risk managers.

Recovery After the Disaster

A strong earthquake may result in numerous building collapses, but partially damaged buildings may be more numerous and may present a greater challenge. A primary question regarding each affected building is whether or not it is safe for rescuers or ultimately for citizens attempting to put things back in order. This determination of safety for all affected buildings, and for those that may have hidden damage, requires a massive effort involving specially trained personnel.

The non-emergency recovery phase of an earthquake actually begins at the same time as the emergency response phase and is often interconnected. Damaged buildings must be inspected and repaired during the recovery phase, but emergency workers often must perform rescues in damaged buildings. This requires building inspectors to quickly check the safety of damaged buildings both as a response activity and as a recovery activity.

After the emergency response phase was completed and after some homeowners had more time to consider their damage assessments and insurance implications, a new problem emerged. At least one fire department reported an increase in arson fires in homes that were badly damaged by the earthquake. Post-earthquake rebuilding required close fire safety supervision. Also, rebuilt homes tended to be much larger than the original structures.

Inspection of damaged buildings

Following any major disaster affecting the safety of buildings, local governments must move quickly to assess overall damage, assess specific structures within an affected area and call in mutual aid when local staffing is inadequate.

State and local: The Office of Emergency Services, the California State Fire Marshal and the Office of the State Architect were three primary state agencies involved in the response to building damage from the quake. The Structural Safety Section of the Office of the State Architect performed damage assessments and evaluated the safety of public schools and hospitals.

Additional inspectors were needed, so the OES State Safety Assessment Plan for Volunteer Engineers was developed. Work on this program began after the 1984 Coalinga earthquake and a draft plan was implemented in the 1987 Whittier earthquake. A new draft plan developed in 1988 by the state in conjunction with the Structural Engineers Association of California and the Society of Civil Engineers incorporated the lessons learned from Whittier. The plan is designed to provide volunteer engineers, registered as disaster service workers, to affected jurisdictions to supplement local building inspection capabilities. They proved to be of invaluable assistance to local building departments.

One month prior to the Loma Prieta earthquake the Applied Technology Council, a California nonprofit firm, published ATC-20, ***Procedures for Postearthquake Safety Evaluation of Buildings.*** The document, which provides guidelines, procedures, forms and placards for post-earthquake evaluation of buildings, was widely used by the volunteer engineers.

To aid this type of mutual aid effort, the California Association of Local Building Officials have subsequently developed a Model Disaster Preparedness and Response Plan for Building Officials. This plan recognizes that telephone communications with employees after an earthquake may be difficult and suggests that an adequate supply of radios be obtained. Radios may include shortwave, CB, walkie-talkies, and cellular phones. Planning for use of the radios should include the necessary operation of antennas, transmitters and backup power supplies. The plan describes disaster management functional responsibilities for building departments, presents a checklist for requesting mutual aid, and lists staff functional responsibilities.

Emergency assistance may be activated at three different levels, based on the severity and scope of the incident. At level I, few structures are damaged and local resources are adequate. Level II is where many structures are damaged but not in a densely populated area. An earthquake will probably be a Level III response, in which damage is widespread throughout densely populated areas, extensive state and Federal assistance will be required, and a local emergency has been proclaimed, and a Presidential declaration of emergency will be requested.

After a local emergency is declared and all local resources are committed, a Building Department Disaster Coordinator channels any mutual aid request through the city or county Office of Emergency Service Coordinator, who forwards requests through the mutual aid system (city to county, to region, to state). Mutual aid is solicited from other building departments, International Congress of Building Officials chapters, or state and Federal agencies.

California State Fire Marshal inspections: Deputies from the office of the California State Fire Marshal (CSFM) at first concentrated on assessing damage to buildings under their jurisdiction, including health care facilities, public schools and state buildings. Two special emergency operations centers were opened, at CSFM headquarters in Sacramento and at the CSFM Coastal Region, which included the earthquake area. Both centers operated under the Incident Command System.

A total of 98 Deputy State Fire Marshals were committed to operations within the earthquake zone. Objectives of the State Fire Marshal mobilization included:

- To participate with the Office of Statewide Health Planning and Development, Department of Health Services, and Office of the State Architect in inspections of health care facilities.
- To prepare a list of all state-owned and occupied buildings categorized by occupancy and county.
- To conduct a telephone survey of each state-owned and operated facility using a standardized list of questions to determine damage.
- To respond to requests for assistance from state and local agencies. The cities of Santa Cruz and Watsonville and the Central Fire Districts of Santa Cruz and Santa Clara

County placed requests through Region II of the Office of Emergency Services for assistance to establish the fire and life safety integrity of various structures in those jurisdictions. Approximately 9000 structures required inspection in Santa Cruz County alone.

In larger buildings, inspection of fire sprinkler systems to assess their condition was also a priority for the deputies. The water supply to many of the systems was found shut off even where there was no damage sustained from the earthquake, possibly by individuals fearing water leaks. These undamaged systems were immediately placed back in service. Only 2.5 percent of the inspected systems received damage. They were reported to the appropriate agency for immediate follow-up. Of the 638 systems inspected, seven facilities suffered water damage or partial shutdown due to broken pipes or leaking fittings caused by the failure of hangers or braces. The most critical failures, which occurred at five of the 16 problem locations, were due to broken water mains. (Beyond the references above, automatic sprinkler systems were not a focus of this investigation and no independent assessment of their particular performance was made.)

Federal: Under FEMA's Public Assistance Program, 75/25% Federal/non-Federal cost share grants are provided to reimburse public agencies and certain private non-profit agencies for response actions and to repair and reconstruct disaster-damaged facilities. FEMA tasked the U.S. Army Corps of Engineers to do preliminary damage assessments and costs estimates in the earthquake area for this program.

In other activities, FEMA provided funding to augment building-permit and inspection staff of local governments in Santa Cruz and Santa Clara Counties. The Corps of Engineers was tasked by FEMA to conduct safety inspections of bridges and piers and to provide technical assistance to Santa Cruz County for investigation of geologic hazards.

CONCLUSIONS / RECOMMENDATIONS

Despite the human and property losses from this earthquake, scientists said that it was not "The Big One" still expected along the San Andreas fault. Will a successful response to the Loma Prieta earthquake mean a successful response to a future, larger event? Not necessarily.

The Emergency Planning and Response Committee of the Seismic Safety Commission believes there is a perception that the State of California and the local governments can handle earthquakes as natural disasters because Coalinga in 1983, Whittier Narrows in 1987 and Loma Prieta in 1989 did not cause a failure of the emergency response system. In fact, however, based on interviews conducted by this committee after Loma Prieta and their subsequent investigation of all three earthquakes, their inescapable conclusion was that the entire system of emergency responders had reached a total saturation point, and if the disaster had been of any larger proportions, the total system would have broken down.

Earthquake experts point out that the area was lucky in several regards this time:

- The epicenter was 60 miles from the area of highest building and population densities in San Francisco and Oakland.
- Schools were closed.
- A higher percentage of the normally mobile population might have been leaving work and in transit at the time of the earthquake. Instead, many area residents apparently left work early and were at home watching television or were at Candlestick Park (62,000 attendance) to see the San Francisco Giants and Oakland Athletics play in the World Series.
- When fires occurred, wind conditions were favorable and did not hamper fire fighter efforts.

- A response plan was in place and training had been conducted for an earthquake in the San Francisco area.

In the Coalinga and Whittier Narrows earthquakes mentioned above, similar good luck was present. Both of those earthquakes began either before the congested business hours or at the end of business hours, resulting in fewer people at risk from collapsing larger buildings.

It must be stressed here that earthquakes are not exclusive to California or the West Coast. An earthquake is sufficiently possible in other parts of the United States that local and state emergency management agencies elsewhere must make preparations now for responding to such a disaster in their jurisdictions.

In the following sections, the findings of this report are categorized and discussed. The categories serve as a reminder of the broad scope of earthquake-related problems that can be expected to result. Many of the findings and recommendations presented here reflect general conclusions reported in other publications focusing on different aspects of this disaster. Local jurisdictions may choose to create a checklist of these and other categories in order to help reconsider the situations resulting from the Loma Prieta earthquake and similar situations that may be expected from other earthquakes or major disasters of any kind.

Planning

Although earthquake locations can be predicted in terms of probability over a period of years, they tend to occur without short-term warning and then can leave behind an overwhelmingly wide scope of damage. Planning and training are critically important, both for local emergency response and for interagency operations. There is certainly no time to work out untested plans after an earthquake strikes.

Most, if not all, public jurisdictions had an emergency response plan, but many agencies and individuals in too many jurisdictions were not sufficiently aware of the plan and their role in it. Many local jurisdictions were clearly not fully aware of all the resources available to them after a major disaster.

Recommendation: Duplicating and approving the state's generic emergency planning guidelines as the Emergency Plan for a local jurisdiction is not sufficient. Jurisdictions must fully consider the guidelines and modify them for unique local needs; this ensures a greater awareness of the plan contents and a greater utility when the disaster strikes. Local plans need to be flagged for periodic updating. Local and state conditions change and the plan must change as a result. Jurisdictions also need to be aware of their neighbors' plans and identify how they can interface. Plans need to provide for the use of all city resources, not just the usual "first responders."

Training

There is probably no better method to prepare for a disaster than an exercise simulating an event designed to test policies and procedures. Many local fire departments and city and county emergency management organizations had conducted earthquake preparedness training on their own. In the months before this earthquake hit, state and Federal agencies had conducted a broad exercise specifically geared toward emergency response to a major earthquake in the San Francisco Bay area. All participants agreed that the exercise was helpful in two ways: it served as focused practice for the real event in October, and it revealed some clear operational deficiencies that could be addressed and modified before the real event.

Recommendation: Additional interagency training needs to be considered in all areas where fault zones indicate a real potential for major earthquake occurrence and damage.

Damage assessment

Earthquakes can vary tremendously in the amount of damage they cause and the amount of emergency services that are immediately required. One of the strongest lessons to emerge from this earthquake concerned the need for an improved damage assessment capability when so many aspects of normal life and emergency response have been disrupted.

Assessment improvements should include methods for quicker accumulation of better information. When seconds count, the initial damage assessment determines priorities for committing resources. The difficulty is that relying on information that can be gathered in the quickest time may be less accurate than information that is reported and acted upon only after verification. The necessity for gathering information and some level of verification is that assessment results provide the foundation for subsequent decisions that affect the overall management of the emergency.

State agencies have a need for improved overview capability that equals local agencies, but state agencies are usually further removed from the source of information. Their methods will be different but will need to be similarly innovative if state agencies are to be more proactive after the disaster strikes.

Recommendation: Local and state agencies should develop new methods to gather good initial intelligence on the scope of an earthquake disaster. New methods are needed because the normal mode of assessment likely will be overwhelmed. These new methods need to include expanded protocols and procedures, use of additional personnel in initial size-up (which may include any local employees with a radio in their cars), and standardization of reporting formats. Because of the need for accurate information, emergency agencies need an independent way of verification of information that is available. The need for verification is not so much regarding the reports of trained local channels as it is regarding reports from the media and from citizens.

Existing satellite technology that allows for detailed review of weather conditions as well as observing military developments such as in Operation Desert Storm may in the future be adapted for speedy review of regional damage from earthquakes or other major disasters. However, this will be only one tool to be used with other methods for damage assessment. Airplanes may be used by larger jurisdictions to provide a quick overview. However, surveillance from the air or satellites may not always be immediately available and may not fully allow the needed assessment after an earthquake because this view is only two-dimensional. “Pancaked” buildings may be hard to spot as damaged from a broad aerial view.

Emergency management

The Loma Prieta earthquake demonstrated that coordination between Federal, state and local agencies is absolutely essential before and after a disaster. It is critical that all agencies are aware of their own role and of each other’s role in a state of emergency. Local jurisdictions were not always aware of the services and resources available to them through the state or of the procedures to obtain that assistance. Local jurisdictions should also be aware of the programs and assistance that are available through the Federal Emergency Management Agency, and they should know the location of their nearest regional office.

The Incident Command System (ICS) has proven to be a useful framework for managing all kinds of major emergencies, but outside the fire services there was a decided lack of uniformity in command and control organization. This resulted in unnecessary confusion, especially during interagency operations, which are common during so large an emergency.

ICS builds an emergency management team by dividing the organizational details into smaller sections with a clear chain of command. An incident commander remains in charge, but the duties and the title can be easily handed off from a first-arriving company officer to a fire chief or to higher levels as the scope of the response widens. At a small incident the company officer may be able to manage all of the needed tasks, including information, safety and liaison. The system provides for expanding support functions as the incident expands, and this requires a plan for delegation of responsibility as well as trained personnel who can assume specific roles when necessary.

The command function includes sections for operations, planning, logistics and finance. Each one can be further subdivided as the incident grows. For example, the command section can be divided into a rescue branch and a suppression branch, each with subdivisions. Despite the success of ICS within the fire service, two of the largest fire departments in the affected area had not adopted this system.

Recommendation: All fire departments, as well as other emergency agencies, should adopt an incident command system. More than a single system is in use, so all jurisdictions should make sure their system is compatible with the system used by other jursidictions. A key factor in expanding an incident command system to fit the complexity of an earthquake disaster in a timely manner is proper training for all potential participants.

The bigger the disaster, the greater the chances that things-especially the important things-will go wrong no matter how much specific training has been given. Consequently, in addition to preparation for managing the specifics, emergency agencies should strive for the flexibility in management structure that will allow them to adapt to the unexpected.

Mutual aid

California's fire service mutual aid system is a model for any state. It is more than a plan: it is a working system tested by numerous broad-scale incidents. The Loma Prieta earthquake, however, was a bigger incident affecting more fire departments than ever before in the life of the system. Some gaps in training for interagency operations were exposed.

The mutual aid system is designed to be quickly responsive to the needs of a requesting fire department. The individuals staffing the state mutual aid center make the assumption that local fire departments will call when they have a need for assistance. In this case the scope of the earthquake resulted in a dramatic and overwhelming upsurge in local incidents. One fire chief assumed that everyone else was equally committed to their own local needs and that mutual aid would not be available. In another case, local damage was so high and communications were so disrupted that a mutual aid request could not be made until days later.

On a California state survey asking if the mutual aid system met the needs of individual fire agencies, 87 percent said it did.

Recommendation: The agencies expressing concerns about the mutual aid system recommended that improvements be made in making the system more proactive rather than reactive. The California Fire Chief's Earthquake Response Committee has requested that "The Fire and Rescue Division of the Office of Emergency Services (OES) should be given the financial support and organizational strength to provide aggressive proactive leadership during a major earthquake disaster. The Loma Prieta earthquake shows us that local fire chiefs do not have the capacity to understand the full magnitude of damages for hours after the initial earthquake. The local prediction for the amount of equipment and personnel needed is difficult at best. OES Fire and Rescue has the ability to scope the bigger picture much quicker than the local fire chief. For that reason our mutual aid system for earthquakes must be different than for normal fire and rescue mutual aid. The response system should be designed so OES Fire and Rescue leadership has the power to request and coordinate regional support based on the magnitude and location of the earthquake epicenter, without waiting for local requests to move the system forward."

Mutual aid reimbursements

An important factor associated with mutual aid operations during the Loma Prieta earthquake was reimbursement for fire resources. Due to the Presidential declaration of a major disaster and the governor's proclamation of a state of emergency, both Federal and state funds were made available for reimbursement of fire units. Reimbursement is not guaranteed following a major disaster, but it can be done under special circumstances and with proper documentation.

Recommendation: Because of the possibility of reimbursement, it is essential that accurate records of mutual aid response be kept by each jurisdiction involved.

Communications

Earthquakes can be expected to disrupt radio and telephone communications at a time when information is especially important.

Although few radio systems failed and major telephone cables were not broken during the quake, the subsequent overload of attempted calls resulted in interrupted communications. Other disruption occurred when fire department and other communications center buildings were evacuated as unsafe. One center was abandoned due to power failure, leaving "9 11" circuits inoperable. One example of failure of the system hardware involved a base station and computer that were not securely braced when the quake hit. Both failed when they overturned.

Operational systems were seriously overloaded during the first critical hours after the event. This is to be expected as a fearful public wants information from authorities and wants reassurance that other family and friends are okay. One result was that a high number of calls received by fire dispatch operators were not to report actual emergency incidents, but were calls seeking information or to notify the fire department of very minor non-fire conditions.

The scope of the response to this earthquake also produced an overload in radio traffic. In some cases this was aggravated by over-excitement and a lack of radio discipline. Another type of communications problem occurred when radio frequencies between some agencies were not compatible. In one case a fire department needed to communicate with military aircraft operating in the same area but could not.

For the radio overload situation, new 800 mHz trunked radio systems being developed today are an improvement. They use computers to automatically select a frequency from several that may be available. Because this is done instantaneously, communications are not interrupted. However, computer software to accomplish this is different with different manufacturers. This limits interjurisdictional use unless all agencies use the same system and software. There must be compatibility between public safety systems to assure mutual aid coordination.

Cellular phones provided an important communications link in many areas. This device is not affected by the loss of electricity nor overloads on public telephone systems. Cellular phones were especially effective within their own networks, but they were subject to the same overload problems when they attempted to call into regular public phone systems.

Mobile communications vehicles were also cited as an important resource in the early hours and days of this incident. Likewise, those not having them frequently noted that they would have been helpful.

Recommendation: A full and comprehensive review of expected communications capabilities following an earthquake is needed. Duplicate and alternate backup communications systems must be developed. Planning for alternate communications systems should include analysis of the future role of satellite communications.

Consideration should also be given to standard operating policy regarding call screening and assignment of priorities to the typical range and high volume of calls received after an earthquake.

Standard operating policy should also include automatic response from off-duty personnel after an earthquake, so that telephone lines are not tied up for that purpose.

Emergency electrical generators

Emergency power is an integral part of emergency communications. Most fire departments reported no problems with their emergency generators, but 20 percent of departments responding to a California state survey indicated a variety of troubles, including failure of the generator to start automatically or at all, breakdown of an operating generator, and generators too small for the actual load needed. Fuel became a problem for some generators, and in one case the quake damaged the fuel supply of a generator.

Review of emergencies in other parts of the country shows similar problems.

Recommendation: The type of problems reported suggests the need for better load-testing emergency generators and for reconsidering the electrical load that may be needed after a major incident. Constant maintenance is also required. Planning should cover several alternative sources for emergency repair and fuel, considering that a large-scale incident puts high demand on regular sources of generator servicing. All generator installations need to be evaluated as to the stability of both the unit and its fuel supply after an earthquake.

If fuel supplies are moved by electrical pumps, alternative methods of getting fuel to the generator must be found. This recommendation applies to pumping fuel for emergency vehicles as well.

Water supplies

Loss of water was a problem for numerous fire departments, especially in the first hours after the quake. Redundancy in water delivery system, which has been a major focus of the San Francisco Fire department response planning, paid off in this event. Breaks in both the municipal water system and the high volume auxiliary water supply system (itself a response to the lessons learned from the 1906 earthquake) inhibited initial fire fighting efforts, causing the fire department to resort to its portable water supply system (portable hydrants and 5-inch hose). Without that backup, the Marina fire would have spread throughout that wide area of multistory wood-frame structures.

Recommendation: Other fire departments should reconsider their dependency on established water delivery systems during an earthquake and plan for disruption of those systems and quick operation of a redundant method of moving water.

Heavy rescue

The number of building collapses-at the Pacific Garden Mall in Santa Cruz and at the Oakland freeway ramp collapse in particular-demonstrated that the training and technology do not yet exist to quickly rescue people from a large collapse incident. A lack of readily available specialized equipment was noted. Fortunately, in the case of the Oakland freeway collapse, a number of industrial businesses were nearby and many quickly volunteered their specialized heavy equipment to aid in the extended rescue effort.

The state operates three heavy rescue/fire units assigned across the state. The state's 1988 Urban Heavy Rescue Act mandates building 15 more units over a lo-year period.

Fire departments indicated after the emergency period that additional selected rescue tools placed on engines or trucks would have significantly increased the ability of these units to operate as urban search and rescue units at the scene of collapsed buildings.

Recommendation: Because of the expense and specialized nature of heavy rescue tools and apparatus, caches of such tools at strategic locations should augment and supplement existing local and state resources. Urban search and rescue specialists are working on specifying the composition of these tool caches. Air bags proved themselves capable of lifting heavy objects. Present heavy rescue/fire units carry them, and it is anticipated that air bag capability will be included in the caches and on the new heavy rescue/fire units being built. Even complete availability of proper equipment will not be effective, however, unless personnel are trained in the use of the equipment and in all aspects of heavy search and rescue.

Medical team coordination

Medical teams at the Cypress Street freeway collapse experienced similar system problems as did other emergency agencies. Medical communications were complicated because the county medical channel was down. Many ambulance radios failed on a company-wide basis, requiring the use of runners in some cases to relay information at the scene. A mobile command unit supplied by one company was never used. Portable radio use was compromised by depleted batteries.

Poor communications capabilities led to other problems. The initial medical operation command post was on the opposite side of the freeway from the incident command post. The medical command post was situated too close to dangerous parts of the freeway and had to be moved for that reason, adding more disruption to the flow of information. During operations there was no system for identifying the lead personnel of the various medical agencies. Other medical volunteers functioned independent of the Incident Command System.

Some ambulance personnel left their units to assist in the rescue operation and could not be found when patients were ready for transport. While participating in the rescues, these ambulance personnel typically had no heavy rescue training and no protective gear, such as helmets and leather gloves.

In the rush to rescue and transport patients, universal precautions for protecting against infectious disease were often disregarded. After the rush, pre-hospital care reports had to be recreated the following week because no one did them at any time during the event.

Recommendation: Medical agencies should establish and maintain a common radio channel for on-scene communications. Organization needs include the use of identifying helmets or vests for key personnel, additional training to emphasize the need to transport earthquake victims to hospitals rather than on-scene treatment, actual transport capability, use of a medical safety officer, and identification of supplies and other resources available for quick movement to the scene.

Building inspections

The number of buildings requiring structural safety inspections was tremendous and required more trained personnel than were available from local and state building departments. Response from engineers as part of the State Safety Assessment Plan for

Volunteer Engineers was of vital importance in handling the amount of work produced by this earthquake.

However, consideration of the details indicates that a lack of training and other preparation for an actual earthquake emergency resulted in many inefficiencies in the mutual aid plan. Assistance was not always requested through the established channels. In other cases arrangements for transportation, food and shelter were not always organized. Some volunteer engineers responded without having the necessary training and required special handling.

Recommendation: The results of building and residence inspections needs to be communicated to other affected agencies. Problems with sprinkler systems in buildings with minimum other damage would be of great interest to the fire department. Another example involved agencies helping the homeless. These agencies normally expect a sudden massive effort to find shelter for those whose homes were immediately destroyed, followed by a dwindling of requests for help in subsequent days. After this earthquake, and as residential inspections continued in some areas, increasing numbers of homes were found to have critical defects even though they did not collapse in the earthquake. This added unexpected demand on the available emergency shelters for the displaced in those areas. Any such developing trend should be communicated the the agencies as early as possible to help them with their preparations.

The scope of earthquake response and recovery is so large that volunteers are of critical importance, yet this resource will not be effective without proper management and training. Pre-emergency preparation by local jurisdictions is the key to successful use of the volunteer engineers and inspection resources. Personnel and equipment and essential buildings must be listed, along with key staging areas. Procedures must be in place to notify inspection personnel. Communications equipment must be ready. Maps, overlays and miscellaneous supplies-such as flashlight batteries-need to be ready to go on sort notice. Signs must also be ready to warn emergency workers and the public of unsafe buildings.

State Fire Marshal operations

Due to the large number of public and residential buildings requiring inspections, deputy state fire marshals were placed in the new role of structural inspectors to determine if hospitals and schools were safe and if residents could return to their homes. New training is being provided to help them in rapid visual assessment of structures. In a high number of cases involving residential inspections, the deputy state fire marshal was the sole face-to-face contact concerned citizens had with any governmental representative during the first week after the disaster.

Deputies were not always adequately supplied when assisting in impacted areas. Disaster preparedness kits that include flashlights, foul weather gear, food, state maps, batteries, AM radios, portable base station radios and hand-held two-way radios are now provided in all CSFM vehicles and offices.

Recommendation: In general, the greatest need for improvement after a CSFM critique was in the delineation of communications between various involved agencies, as well as a need for clarification of individual CSFM staff roles at both the Emergency Operations Center and the State Operations Center. In response to this the CSFM has instituted an interim Emergency Operations Plan until a new approved final plan is in place. Additional training in the Incident Command System will also be offered.

Non-structural damage

Earthquake studies indicate that more people are injured in earthquakes due to non-structural hazards than from actual building failures. This is significant, since many of the mitigation measures that can alleviate these hazards are fairly inexpensive. The implication for fire departments and other emergency agencies is that this non-structural damage can interfere with full response to calls as much as serious structural damage.

Fire departments reported numerous incidents where their equipment came loose from its place of storage or mounting. One agency noted that its communications center tape recorder fell and was damaged. Many agencies kept electrical power but lost computer terminals and communications equipment when items fell onto them and they fell over.

Recommendation: Pre-quake attention to securing shelves, files, cabinets and fixtures such as water heaters at fire stations and other emergency facilities can result in less damage and fewer injuries to emergency personnel attempting to maintain operations in them, as well as a significant reduction in downtime after the quake. This will contribute to speedier service to a public that may be in dire need of assistance.

Attention to these contents-related items does not eliminate the additional need to have the structural condition of fire stations and other facilities checked after an earthquake, especially if any visible damage is apparent.

Logistical support

Supplies to support response and recovery operations after the earthquake were quickly consumed and were harder to replace. Not all jurisdictions had an adequate supply of medical supplies, office supplies and such essentials as flashlight batteries. Some supplies were especially important to the responding mutual aid teams, which were dependent on having maps, hand tools, protective clothing, clipboards, placards and forms.

A number of mutual aid teams arrived quickly by airplane, but they discovered that a lack of supplies hampered their efforts. They learned that it would have been more effective to drive a convoy of the mutual aid teams to the scene, being able then to bring more equipment and supplies. Teams from Los Angeles did bring boxes of their own supplies when they responded by plane.

Some of the logistical support problems encountered were more important than unusable flashlights. The large number of injuries caused an overload on private sector EMS/ambulance resources. All available units were in constant use, yet additional victims needed transportation. This forced fire departments to find special solutions to special problems. The San Francisco Fire Department's solution was to use taxis to transport some people to hospitals.

A different type of logistical problem occurred with the premature return of electricity service. This can be a danger in conjunction with unrepaired gas leaks and insufficient time and personnel to check all systems for safety.

Recommendation: Each agency needs to reconsider the possibility that the complications from a major earthquake (extremely high demand for emergency services, communications disruptions, loss of utilities, lack of cached materials, inadequate available personnel and transportation resources) will disrupt its ability to resupply field units with basic tools, equipment and consumable items. Preparations should be made to acquire and store the material that is vital both to immediate operations and ultimate recovery. Pre-incident planning often considers the major factors of emergency response, but the more mundane items, such as flashlight batteries, pens and informational signs, must not be forgotten.

Public information

A lack of interaction with media personnel and the provision of timely, accurate public information was a serious deficiency after the earthquake.

Many radio stations rushed to broadcast immediate reports with unconfirmed and incorrect information. Media personnel were said to have interfered with the evacuation of a hospital during their attempts to interview patients. Reporters and cameras became a problem at the Oakland freeway collapse, where their numbers and the instability of the scene required limiting their access. An unusual number of media personnel were in San

Francisco to cover the World Series, and many of the media problems involved these individuals who did not have a familiarity with the local scene and ready access to local sources. These individuals were more likely to go beyond the regular media efforts at finding information or video that their editors or producers would use.

This is not the first time these situations have developed. After the 1983 Coalinga earthquake, a report of the Seismic Safety Commission noted: "The news media was an extremely disruptive influence. They frequently hindered the response actions in their efforts to obtain camera coverage or to interview rescue workers, city officials or other response officials."

However, similar complaints of non-cooperation were heard from the media. Local officials have the responsibility to provide accurate and timely information to the affected public.

Recommendation: It is imperative that local media be included and encouraged to participate in the pre-event planning and training. A close working relationship and rapport between local officials and the media is essential to the successful dissemination of accurate information to the public on a timely basis. Designation of a public information officer is one factor to improve that working relationship.

Citizen volunteers

In many cases citizen volunteers performed some of the first rescues before fire and medical personnel could arrive. Most of these untrained volunteers just found themselves at the scene of a disaster and decided to help someone else in need. They used makeshift tools where necessary and scrambled into broken structures without regard for their own safety.

Later, press reports drew other volunteers+ften with special skills or equipment-to the scene of publicized incidents and they joined professional crews already at work. Still others volunteered with supplies and specialized equipment thought to be needed. Civilian equipment, by its volume, helped more of the rescuers onto the Cypress Street structure than fire department ladders. Civilian forklifts were a quick and common method of removing victims from the structure. When light faded the first evening and a 1.5mile-long area needed emergency illumination, contractors arrived with extra generators, extension cords and lighting units.

Citizen volunteers often worked at great personal risk. In some cases the risk exceeded the needs of the situation. In some cases they were not needed and, though well-intentioned, were in the way. Because of their volume, no one was able to monitor or supervise all of the people trying to help. In the confusion of the first night it was at times hard to identify who was an essential volunteer and who was merely curious and extraneous.

Recommendation: Citizen volunteers provided critical services, skills and equipment in the beginning of this disaster response, but more planning is needed to better manage this resource.

Emergency personnel anxiety and stress

The anxiety levels of emergency workers over lack of knowledge of the condition and safety of their own family members was understandable during the first hours of this emergency and was compounded by the interruption of telephone service.

Off-duty personnel with even slightly damaged homes experienced a special distress when facing the dilemma of family needs versus the duty to return to the fire department to help other members there and the community at large.

At least one department reported holding all personnel on duty for seven to ten days, due to the high risk of fire and the massive municipal water supply failure. Long hours and mass destruction contributes to post-incident stress syndrome in emergency workers and possibly anyone subjected to the pressures associated with an earthquake. The effects are of more concern after the incident than during it, when training and activities keep the worker focused on positive responses.

Recommendation: To help relieve the anxiety levels of on-duty emergency personnel after a disaster possibly affecting their families and property, agencies can do what is necessary to determine the condition of those families. One person assigned to do nothing but track down family information both gathers important information and also reassures those personnel still waiting for a family update. When communications systems return to operations or when all families are accounted for, the assigned person can return to his/her emergency duties.

Critical incident stress debriefing has proved to be effective in aiding emergency workers involved in major disasters. Because the timing of this type of aid is essential, emergency agencies should make advance preparations for providing prompt debriefing when needed.

APPENDIX

EARTHQUAKE POTENTIAL ELSEWHERE IN THE UNITED STATES

Although experts believe the West Coast is still at high risk for another larger earthquake, they also warn that the potential for a major earthquake also exists elsewhere in the United States in the Midwest, Northeast and Southeast, as well as Alaska. Considering at least three seismic areas in the eastern half of the country, scientists are certain that a Loma Prieta-size earthquake will occur somewhere in the East within the next 30 years. Those scientists are equally certain that such a disaster will far exceed the damage from the Loma Prieta event, due to the nature and age of the buildings, the vulnerability of utility lines, the absence of seismic building codes, the adverse climate and the lack of maintenance of the infrastructure in the East.

FEMA is sponsoring two exercises, similar to “Response 89” in California, in the New Madrid fault area (described below under the heading Midwest). “Response 91A” is a tabletop exercise, with exercise activities at seven state emergency operations centers, four FEMA regional operations centers, FEMA headquarters, and two disaster field offices. “Response 92,” scheduled for fiscal year 1992, is anticipated to be a more comprehensive exercise.

Additionally, FEMA has a planned exercise program for high-risk areas throughout the United States. “Response 90” was an exercise for the Wasatch fault in Salt Lake City, Utah and “Response 91B” will exercise the Puget Sound area in Washington. “Response 93” and “Response 94” are planned for California.

Midwest

The New Madrid fault zone of Missouri, about 150 miles southeast of St. Louis, is of particular concern. This area experienced some of the most violent and wide-ranging earthquakes ever occurring in this country. That they occurred in late 18 11 and early 18 12 leads some people falsely to disregard the potential for a reoccurrence today. That series of earthquakes flattened hundreds of square miles of forests and changed the course of the Mississippi River. Few people died because of the sparse population and low-rise construction common at the time. If the same size earthquake (magnitude 8) hit the area today, an estimated 12 million people would be affected.

Different geological conditions in California and the New Madrid fault zone would produce different results from the same size earthquake. Homogeneous bedrock associated with the New Madrid fault zone and other Eastern areas would transmit the damaging force of the earthquake for a greater distance. Both Memphis and St. Louis would be hard-hit by a 7.1 magnitude event similar to the Loma Prieta earthquake. Experts predict that the same earthquake at New Madrid would cause perhaps 20 tunes the area of damage as in California.

The question seems to be “when” rather than “if.” Before the year 2000, according to seismologists, the probability of a 6.5-magnitude earthquake along the New Madrid fault zone is 50 percent. Looking at a 50-year period, the probability increases to 100 percent.

Seismic building requirements in the Midwest are not as restrictive as in California, however. Perhaps 75 percent of commercial buildings in St. Louis are said to be of unreinforced masonry, which has a very poor record of survival in earthquakes.

Several major oil and gas transmission pipelines pass through or near the New Madrid fault zone. These pipelines carry an average of 600,000,000 barrels per year and would be highly subject to damaging stresses during an earthquake. Spilled oil products could contaminate a wide area of watershed supplying water to the area.

Southeast

Charleston, South Carolina, has a 50 percent probability of a major earthquake in the next 50 years. A previous disastrous quake occurred in 1886 and destroyed or damaged a majority of the buildings in the city. The same event today would cause an expected several thousand deaths. Most of the schools were not built to any seismic specifications, and many office buildings are of older, unreinforced masonry construction.

Northeast

Several hundred low-to-moderate (up to magnitude 5) earthquakes occur every year in the Northeast, especially in New York State. An 1884 earthquake occurred near Rockaway Beach, 17 miles from city hall in New York City. Much of the construction in Queens is over soft sands similar to those in the San Francisco Bay area.

A special danger related to any earthquake in the New York City area is that an estimated 50 percent of all buildings are of unreinforced masonry. The probability for a major earthquake near New York City is low, but the damage from an earthquake there with a magnitude of 6.0 would dwarf any previous event.

Multiple-span bridges with deficient bearings, non-ductile substructures and under-reinforced footings or piles are vulnerable to seismic damage, and a majority of these are in the Northeast. Of all the bridges in New York State, 74 percent are of this type. The situation is made worse by weather conditions and poor maintenance in the Northeast. The Tappan Zee bridge across the Hudson River just north of New York City is very similar to the eastern spans of the San Francisco-Oakland Bay Bridge, where a collapse occurred during the Loma Prieta earthquake.

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