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On January 17, 1994 at 4:31 a.m., a magnitude 6.6 earthquake struck the Los Angeles metropolitan area. Epicentered in the San Fernando Valley town of Northridge, California, the earthquake caused serious damage to buildings and sections of elevated freeways; ignited at least one hundred fires as it ruptured gas pipelines; and disrupted water supply systems. Fifty-seven people died, another 1,500 were seriously injured, and 22,000 were left homeless. Over 3,000 buildings, most of which were residential structures, were declared unsafe for reentry due to earthquake damage. This report presents the findings of numerous investigators who visited the Northridge area following the earthquake. Topics include seismology, geology and geotechnical issues; highway bridges and buildings; lifelines and utilities; nonstructural building elements; emergency response; and societal impacts. In addition, the authors provided some tentative conclusions based on their observations and experience in past earthquakes. These conclusions and recommendations are included in a separate section at the end of the report. Many of the observations and conclusions contained in this report are preliminary; it is not intended to be the final word on the earthquake, rather its purpose is to provide an additional increment of new information beyond that contained in earlier reports and to set the stage for further investigations.

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NATIONAL CENTER FOR EARTHQUAKE ENGINEERING RESEARCH

State University of New York at Buffalo

The Northridge, California Earthquake of January 17, 1994: General Reconnaissance Report

Edited by

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NOTICE

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Edited by

J.D. Goltz[1]

March 11, 1994

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ABSTRACT

On January 17, 1994 at 4:31 a.m., a magnitude 6.6 earthquake struck the Los Angeles metropolitan area. Epicentered in the San Fernando Valley town of Northridge, California, the earthquake caused serious damage to buildings and sections of elevated freeways; ignited at least one hundred fires as it ruptured gas pipelines; and disrupted water supply systems. As a consequence, 57 people died, another 1,500 were seriously injured, and 22,000 were left homeless. Over 3,000 buildings, most of which were residential structures, were declared unsafe for reentry due to earthquake damage. Los Angeles, a city which has extensively prepared itself for earthquakes, found that it had experienced the most destructive event since the 1906 San Francisco earthquake. Direct economic losses are estimated currently at over $20 billion.

This report is the product of many authors representing several disciplines and, while not a final assessment of the topics addressed, it represents an interim evaluation of the performance of numerous structures and lifelines. In addition, the report includes sections on emergency response and societal impacts. Many of the observations and conclusions contained in this report are preliminary; it is not intended to be the final word on the earthquake, rather its purpose is to provide an additional increment of new information beyond that contained in earlier reports and to set the stage for further investigations.

This report is one of three NCEER reports resulting from reconnaissance activities following the Northridge, California earthquake. The other two reports are: **The Northridge, California Earthquake of January 17, 1994: Performance of Highway Bridges** and **The Northridge, California Earthquake of January 17, 1994: Performance of Gas Transmission Pipelines**.

ACKNOWLEDGMENTS

This report and the reconnaissance effort which made it possible are a collaborative effort of many investigators and institutions. Principal participating organizations include the Applied Technology Council and EQE International. Sponsorship of these activities was provided by the National Science Foundation, the Federal Highway Administration and the New York State Science and Technology Foundation through the National Center for Earthquake Engineering Research.

The United States Geological Survey and faculty members of the California Institute of Technology contributed to Section 2 on seismology, geology and geotechnical aspects.

The material presented in Section 3 on highway bridges was obtained by a reconnaissance team organized by Christopher Rojahn of the Applied Technology Council and led by Ronald Mayes of Computech Engineering. The four member team visited damaged bridges in the Los Angeles area on January 18-19, 1994. The generous assistance of Caltrans to this reconnaissance effort is greatly appreciated.

Information for Section 4 on Southern California lifelines was provided by Ronald Tognazzini of the City of Los Angeles, Department of Water and Power, Dennis Ostrum of Southern California Edison and Ed Matsuda of Pacific Gas and Electric.

Several individuals provided data, photographs and editorial suggestions for Section 6 on emergency response. Robert Eplett of the Governor's Office of Emergency Services (OES) contributed the photographs used in figures 6-1, 6-2, 6-3 and 6-4. Cheryl Tateishi, Richard Ranous, Mark Ghilardicci and Michael Douglas, also with OES, provided information and served as reviewers. Irv Johnson of the Emergency Medical Service's Authority and Frank Borden of the Los Angeles City Fire Department provided valuable information and suggestions.

CONTRIBUTORS

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Section 7 by Kathleen Tierney, University of Delaware.

Conclusions and Recommendations

Section 8 is a compilation of conclusions and recommendations made by the individual authors.

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SECTION 1
INTRODUCTION

At 4:31 a.m. on January 17, 1994, an earthquake struck the Los Angeles metropolitan area killing 57 and injuring approximately 9,000, with 1,567 requiring hospital admission. Over 3,000 buildings, the great majority of which were residential structures, were declared unsafe for reentry due to earthquake damage. The magnitude 6.7 earthquake was centered near Northridge in the San Fernando Valley area of the City of Los Angeles with strong ground motion extending about 40 miles from east to west and 30 miles north to south from the earthquake's epicenter. The cities of Los Angeles, Santa Monica, Simi Valley, Santa Clarita and Fillmore were especially hard hit. The earthquake was the latest of several damaging events to strike Southern California and, if preliminary damage estimates prove accurate, the costliest earthquake in the nation's history.

The Northridge earthquake occurred just three weeks before the anniversary of the San Fernando Valley earthquake of February 9, 1971, and the two events bear many similarities. They were similar in magnitude and duration and the zones defined by aftershocks from the two events overlap in the eastern San Fernando Valley. The two events were also alike in their impacts on the population and built environment. In fact, some of the same structures damaged in 1971, including the intersection of Interstate 5 and State Highway 14, three San Fernando Valley hospitals and important water and power facilities, were once again impacted by the January 17 earthquake.

Despite the similarities with other earthquakes experienced in the region, the Northridge earthquake, it's impact and the community's response to it was unique in a number of respects. This earthquake may provide the first important test of the effectiveness of retrofit ordinances for unreinforced masonry buildings passed by local jurisdictions in metropolitan Los Angeles. The heavy impact of the earthquake on certain types of structures and facilities will cause close scrutiny of design criteria especially for freeway bridges, parking structures and utility equipment. Equally important will be a thorough review of nonstructural performance, particularly in hospitals and schools.

From the standpoint of response, the State of California has recently promoted use of the Operational Area concept and a Standardized Emergency Management System to rationalize coordination and communication between governmental units in major emergencies such as this earthquake. Post-event assessments will examine the effectiveness of these innovations. The Northridge earthquake also marked the first earthquake in which real and near-real time data were available for response purposes. This information consisted of source parameters of magnitude and location, intensity maps and loss estimates, including projections of casualties, displaced persons and dollar losses from both ground shaking and fire.

This report presents the findings of numerous investigators who visited the Northridge area following the earthquake. Topics include seismology, geology and geotechnical issues; highway bridges and buildings; lifelines and utilities; nonstructural building elements; emergency response; and societal impacts. In addition, the authors provided some tentative conclusions based on their observations and experience in past earthquakes. These conclusions and recommendations are included in a separate section at the end of the report.

SECTION 2
SEISMOLOGY, GEOLOGY AND GEOTECHNICAL ASPECTS

2.1 Seismological Observations

On the morning of January 17, 1994 at 04:30:55.4 (PST), an earthquake occurred near Northridge in the San Fernando Valley, 35km northwest of the Los Angeles central business district in Southern California (34° 12.7'N 118° 32.3', depth 18km). The preliminary moment estimate determined from regional surface waves and teleseismic recordings was 1 to 1.5 X 10^{26} dyne-cm, which gives a moment magnitude of M_w 6.7. The preliminary local magnitude determined from telemetered strong-motion instruments in Southern California was M_L=6.4. Both the first-motion focal mechanism from local stations and the teleseismic mechanism show a thrust fault on a plane trending in a northwest direction (Figure 2-1). The pattern of aftershocks reveals that the plane dipping toward the southwest is the fault plane, and its dip is 40° to 50°.

The strong ground motions from the Northridge earthquake were recorded on many instruments within the Los Angeles area. Peak accelerations of free-field instruments were generally 0.5g to 1.0g in the aftershock area and decreased to 0.1g at distances of about 50km. Several sites close to the epicentral area recorded accelerations over 1g. The extensive damage caused by this earthquake emphasizes the need for better understanding of local site conditions that affect ground motion. More than 75 instruments were deployed following the mainshock to study these site effects. Seismic instruments were placed at many of the strong motion instrument sites that produced significant records of the mainshock. Also, many of the severely damaged areas in Northridge, Sherman Oaks and Santa Monica were instrumented, as well as the collapsed bridge sites at the SR14/I-5 interchange, SR118 near Woodley, and the I-10 Santa Monica Freeway near La Cienega Boulevard.

Thousands of aftershocks occurred in the two month period following the earthquake including six M5, forty-three M4 and 284 M3 events as of March 15. The locations of the aftershocks are distributed across an area about 30 x 20km (Figure 2-1). These locations are clearly deeper toward the south and in cross-section (Figure 2-2), reveal a plane dipping toward the southwest which is interpreted to be the fault plane for the earthquake. This plane extends from the mainshock hypocenter at 18km upward toward the surface. Preliminary analysis of teleseismic data indicates that most of the slip on the fault plane occurred at depths below 5 to 10km with relatively little slip of the shallow portions of the fault.

The location of the fault plane, as inferred from the aftershock distribution, does not correspond to any mapped geologic fault. The earthquake did occur, however, within a system of known thrust faults that extend along the northern edge of the San Fernando Valley. Most of the

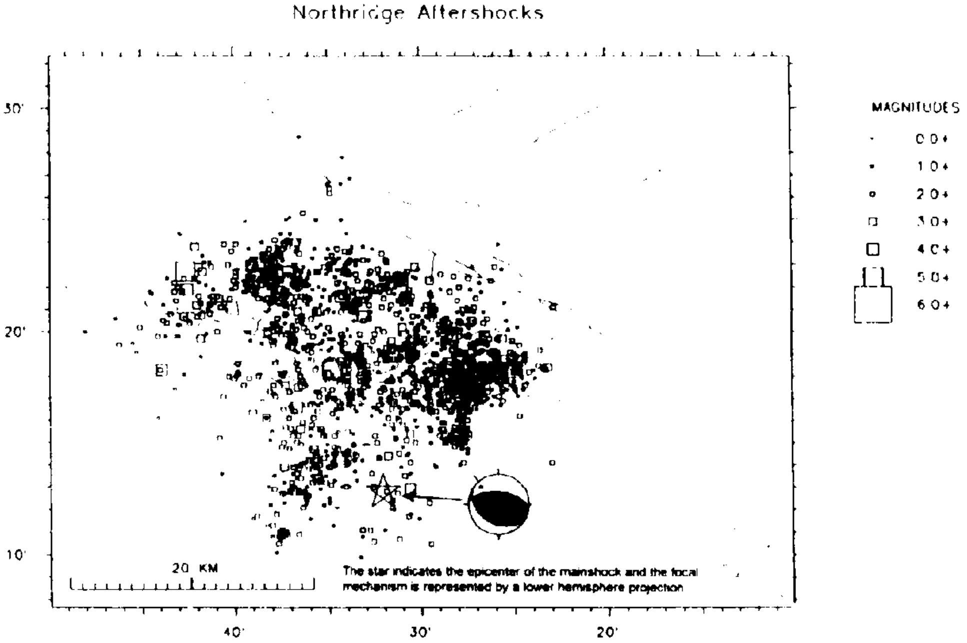


FIGURE 2-1 Locations of Aftershocks from the Northridge Earthquake

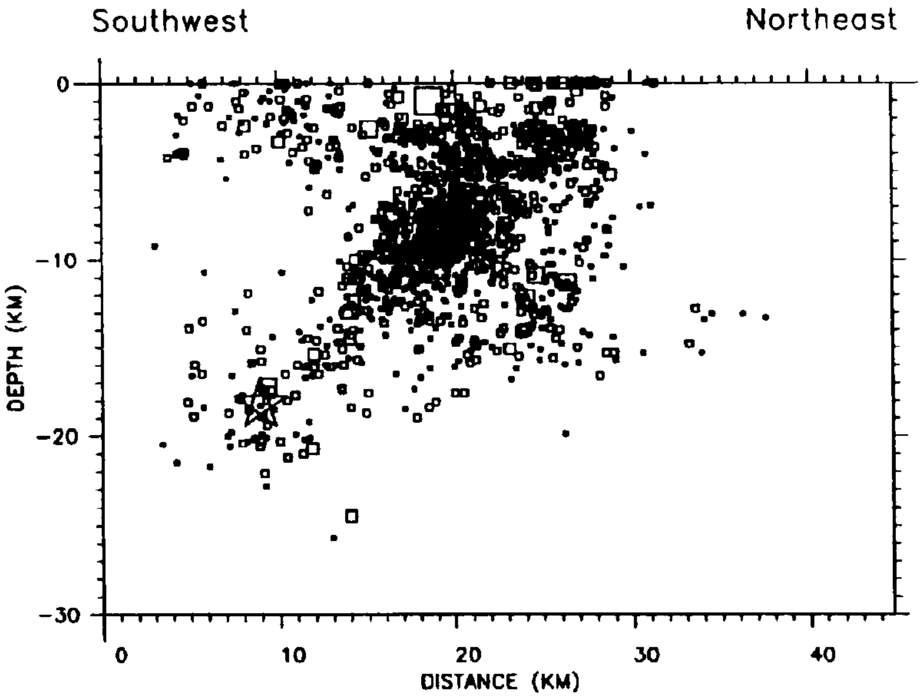


FIGURE 2-2 Cross-section of Hypocenters Through the Eastern Half of the Aftershock Zone - the Section is Oriented at N30°E

mapped faults have northerly dips, although there are several structures, such as the nearby Oak Ridge system, that have southerly dips.

Many of the aftershocks are located on or close to the rupture plane. However, there are also many off-fault events that have a variety of focal mechanisms. One example is the M5.1 earthquake of January 29 which was a shallow strike-slip event above the main rupture plane. Portable instruments recorded accelerations of up to 0.8g from this earthquake.

Real-time information about the mainshock and aftershocks were broadcast to 15 members of the Caltech-USGS Broadcast of Earthquakes (CUBE) program. This project is a cooperative effort to provide rapid earthquake information in Southern California. CUBE participants include governmental emergency response agencies, water and power utilities, railroads, and other private sector organizations. Earthquake locations and magnitudes are disseminated via pagers and computer displays throughout Southern California and to other parts of the country. Generally, information is received within five to eight minutes of the earthquake occurrence. Because of various problems encountered at the time of the Northridge earthquake, information about the mainshock was relatively slow in being released. However, data on the first aftershocks were being broadcast within 15 minutes of the mainshock.

2.2 Geodetic Observations

Results from re-surveys of benchmarks, using the Global Positioning System (GPS), reveal the static displacements due to the earthquake at 15 sites. In the aftershock region, there were vertical uplifts of 40 to 50cm and horizontal motions of 2 to 20cm. These movements are consistent with the fault geometry derived from seismological observations of a plane dipping toward the southwest at about 40°. Preliminary modeling of the data indicate that there was a slip of 2.5 to 3.5 meters on a 10 x 10km patch of the fault. The motion was primarily thrust faulting, and most of the slip occurred at depths of greater than 6km.

2.3 Geological Observations

Two areas of surface cracking observed immediately after the earthquake are being studied. It is unclear if these cracks are direct results of tectonic faulting or due to ground shaking. The small amount of observed surface cracking, however, is consistent with the geodetic results that there was not a large amount of slip on shallow portions of the fault.

The most extensive area of ground deformation was in Potrero Canyon on the north side of the Santa Susana Mountains near the northern edge of the aftershock zone. A series of discontinuous tension cracks and normal faults with displacements of up to 60cm were observed on both the north and south sides of the canyon extending for about 3km. Evidence for compressional features with vertical displacements of 8 to 20cm were also observed along the south margin of the canyon. None of the deformations were associated with any previously mapped surface fault.

A second system of small cracks was studied along a 5km zone in Granada Hills, a region that had numerous water and gas main ruptures caused by the earthquake. The complex series of cracks had both extensional and left-lateral features. Some of the deformation occurred in association with buried stream channels but may also represent secondary faulting on the Mission Hills fault.

There were extensive landslide occurrences in the younger sediments of the western Santa Susana Mountains, Oak Ridge and Big Mountain areas. Rock falls have choked the ravine bottoms of many canyons in the Santa Susana Mountains. These were of some concern following the earthquake since heavy rains could saturate the material, causing it to mobilize into debris flows that threaten structures near the mouths of the canyons.

2.4 Geotechnical Aspects

The geotechnical aspects of the Northridge earthquake include: soil amplification, topographic effects on the intensity, soil-structure interaction, frequency and duration of ground motion, soil liquefaction, permanent ground deformation, and landslides. Only the most significant effects will be described.

The soil and geologic conditions under a particular site have been known to affect the ground motion recorded at the surface, that is, the motions which excite structures. In some past earthquakes, such soil effects have had spectacular consequences, for example in Mexico City in the 1985 earthquake and in the San Francisco Bay area in the 1989 Loma Prieta earthquake.

In the Northridge earthquake, such soil effects are clearly less obvious. The San Fernando Valley as well as the Los Angeles basin are mostly underlain by deep and stiff soils. However, differences in the soil thickness and stiffness from place to place do exist, so the potential for different soil effects is real. Indeed, the recorded motions that have so far been made available (from California Division of Mines and Geology's Strong Motion Instrumentation Program (CSMIP), U.S. Geological Survey and University of Southern California arrays) show appreciable differences in the peak values of ground acceleration from place to place at about the same distance from the source (see Figure 2-3).

Along Interstate 10, the peak accelerations vary from 0.93g near Santa Monica Beach (24km from the epicenter) to 0.27g at the Century City-Los Angeles County Club site (20km from the epicenter), with the Hollywood Storage building site reaching an intermediate 0.41g value (23km

5th CSMIP Quick Report of January 25, 1994

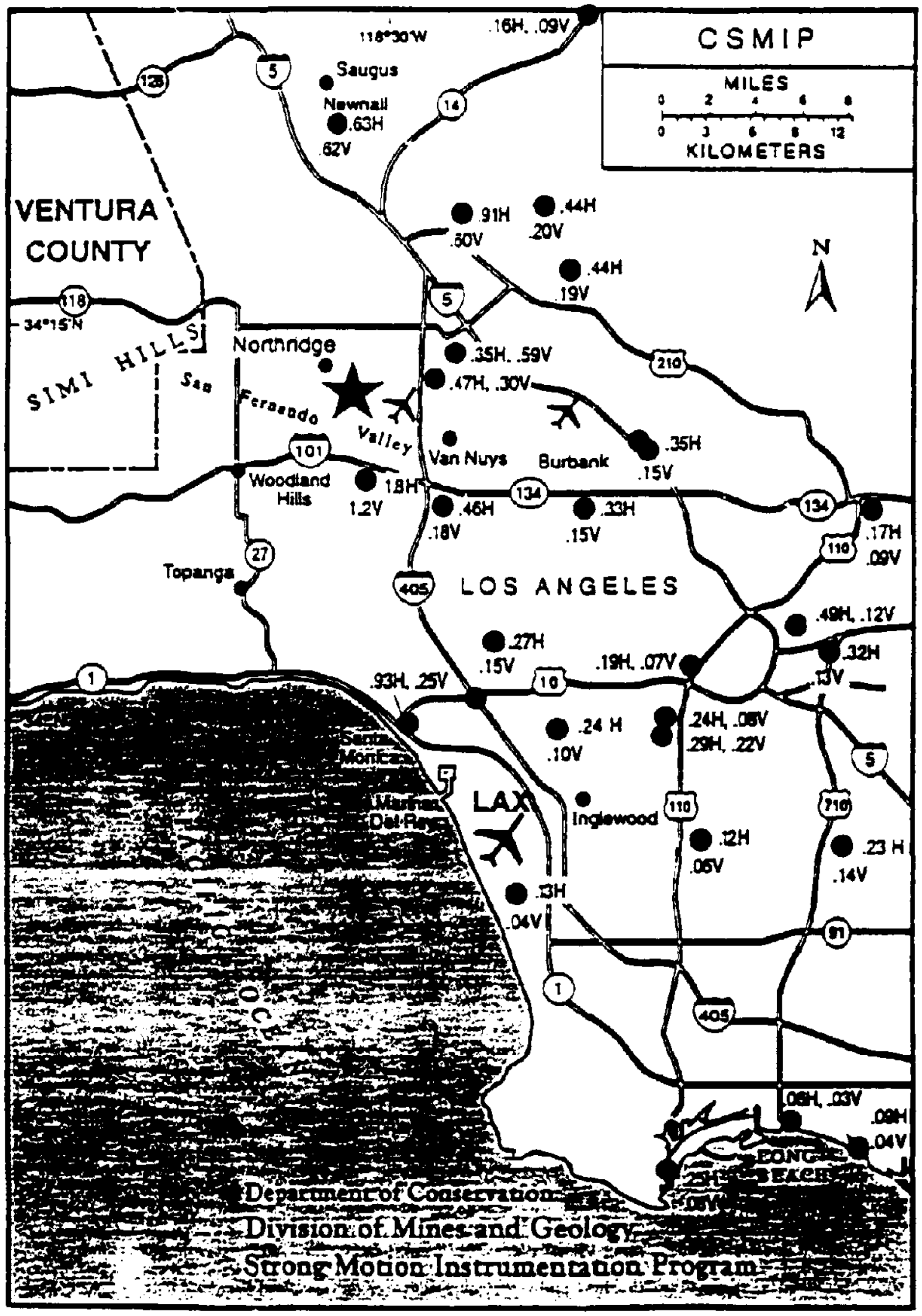


FIGURE 2-3 Map of Peak Accelerations from CSMIP [1]

from the epicenter). Since these sites are at similar distances, and in the same general direction from the fault, soil amplification effects appear to be the most likely reason for the large differences in the recorded accelerations.

In the Long Beach area, nearly 60km from the epicenter, several records exhibit peak values in the range of 0.06g to 0.09g. Yet, nearby, at the base of the Vincent Thomas Bridge, the recorded peak acceleration was 0.25g. For the reasons stated above, soil amplification is again a very likely culprit.

In the San Fernando Valley, and in its northern extension, peak accelerations vary widely from point to point, almost regardless of the epicentral distance. Examples include Olive View Hospital 0.91g (distance = 15km), Arleta Nordoff Avenue Fire Station 0.39g (distance = 9km), Newhall 0.63g (distance = 19km) and Sepulveda VA Hospital 0.94g (distance = 8km). Soil amplification effects may have played a role in such differences, although, so close to the source, other seismological factors may have contributed as well.

A definitive answer on the above and other cases must await the results of comprehensive seismological-geotechnical studies.

Topographic effects on ground motion seem very likely in at least two cases. The first is at the Pacoima Dam (17km from the epicenter), where two records, one downstream (free field) and one at the base of the dam have peak accelerations of about 0.45g. On the two steep abutments, accelerations in excess of 1g were recorded. The 1971 San Fernando earthquake also produced a very high acceleration (1.2g) at a point just above one of these abutments. That peak had been attributed to topographic effects.

The second instance of topographic effects on ground motion is at the Tarzana Cedar Hill Nursery located about 7km from the epicenter. The ground motion record at this site displays an unusually large number of pulses with peak acceleration values of 1.82g and 1.01g in the two horizontal directions, and of 1.18g in the vertical direction. Figure 2-4 shows the traces of ground motions recorded in Tarzana. Such anomalous ground motions had also been recorded in Tarzana during the 1987 Whittier earthquake. Tarzana is located in the northern foothills of the Santa Monica Mountains. Local soil and, especially, topographic conditions at the recording station, may have played an important role in amplifying of the rock motions at this site.

Soil amplification and topography may also have played a significant role in contributing to the failures of a number of bridges, buildings and parking garages since many similar structures in other locations within the epicentral region survived. These potential soil amplification and topographic effects should be investigated using site-specific geotechnical and geologic data before definitive conclusions can be drawn and practical recommendations made.

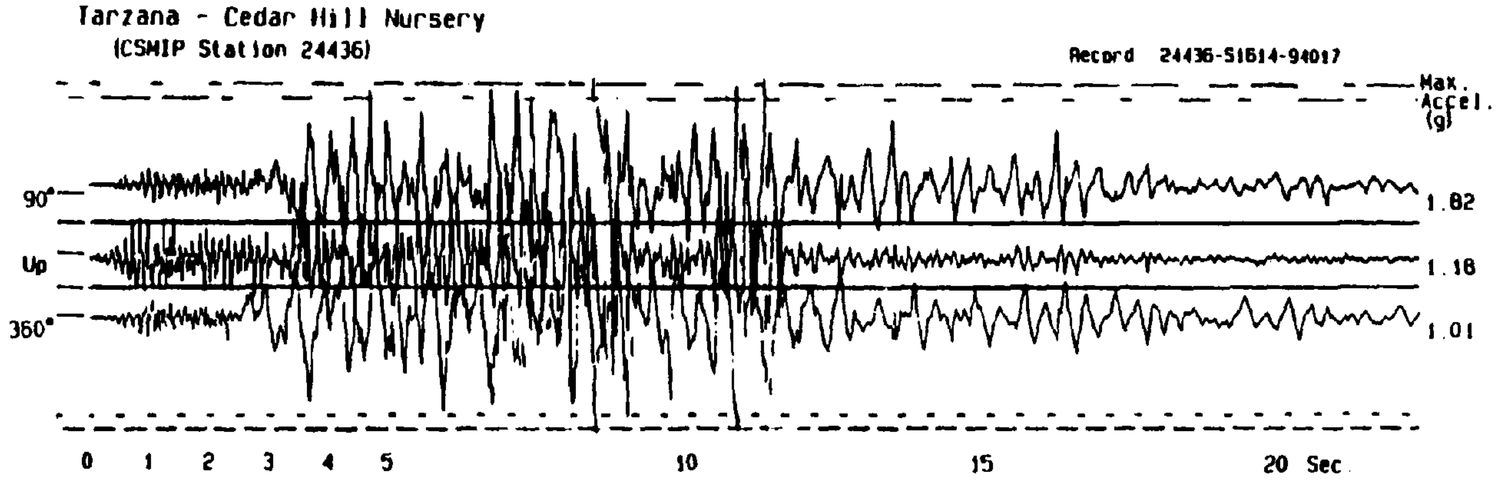


FIGURE 2-4 Ground Motion Records from the Recording Station in Tarzana [1]

Soil-structure interaction may also have played a role in the seismic performance of bridges and buildings. For instance, in nearly all cases where accelerations were recorded in both the parking lot (free-field) and the base of the structure, the measured peak accelerations were different. In buildings, the peak base motion was usually only about 80% of the free-field peak. Examples include the Hollywood Storage building (0.29g at the base versus 0.41g at free field) and University of Southern California Hospital (0.37g at the base versus 0.49g at the free field).

On the other hand, in the few bridges where such pairs of records were available, the opposite seems to be the case: the motion at the base of the pier has larger peaks than the motion of the free field. Moreover, the interaction between the abutment retaining wall and a bridge and the bridge deck and piers, although difficult to ascertain with a simple visual observation, could have played a role in some of the bridge failures (e.g., State Route 118 – Mission-Gothic Undercrossing, I-10 Santa Monica Freeway – Fairfax-Washington Undercrossing). The abutment fills behind many of the failed bridges subsided significantly, contributing no doubt to the "distress" of the bridge. Comprehensive and systematic studies are needed to provide a better understanding on these soil-structure interaction issues that may be vitally important to seismic design.

Manifestations of geotechnical failures and damage could be observed at many different locations as far away as 50km from the general epicentral region. Figure 2-5 shows the approximate location of sites where liquefaction and landslides were observed. Evidence of liquefaction has been observed in the Simi Valley 15km northwest of the epicenter. Also, soil liquefaction in the toe region of Highway 127 near the town of Piru may have contributed to its failure. In the parking lot of the Santa Monica Pier, liquefaction of the underlying sands caused extensive cracking of the pavement and ejection of sand, as shown in Figure 2-6.

In Redondo Beach, about 45km from the epicenter, evidence of liquefaction of the sands, used in the construction of the pier, was observed. Figure 2-7 shows a 1.50 meter high retaining wall that was constructed upon a rock berm. The top of the rock berm is estimated to be about three meters above the mudline. There is evidence of lateral movement at and near the toe of the rock berm as shown by the tilting of the mooring piles (Figure 2-8). Furthermore, the ground surface level on the pier experienced significant subsidence. Figure 2-9 shows one of the two buildings on the pier that is founded on a concrete slab that experienced about 13 inches of settlement relative to the section of the pier that did not move. The failure mode of this pier is not yet clear. Further investigations of the geotechnical data and the profile geometry may reveal the mechanisms of this failure.

There were a number of rock slides that were observed mostly in the region north of the epicenter. Figure 2-10 shows photographs of typical rock slides. In Santa Monica, along the Pacific Coast Highway, spectacular landslides occurred damaging many of the homes built on cliffs overlooking the ocean. Figure 2-11 shows a section of this landslide. Also, in Simi Valley,

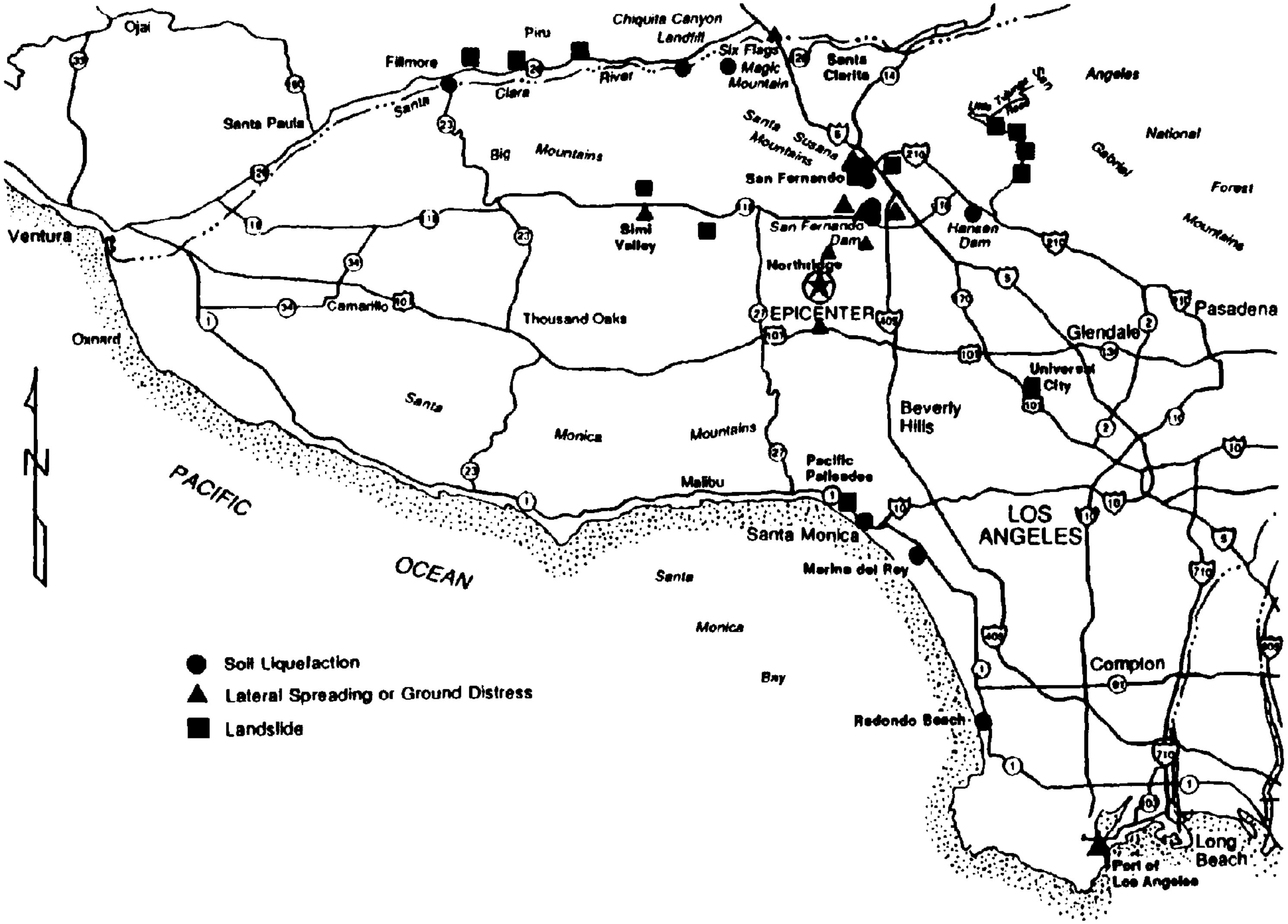


FIGURE 2-5 Earthquake Affected Region with Locations of Geotechnical Observations [2]

FIGURE 2-6 Liquefied Sand Ejected from Cracks in the Pavement of the Parking Lot in Santa Monica Beach

FIGURE 2-7 Movement of the Retaining Wall of the Pier in Redondo Beach

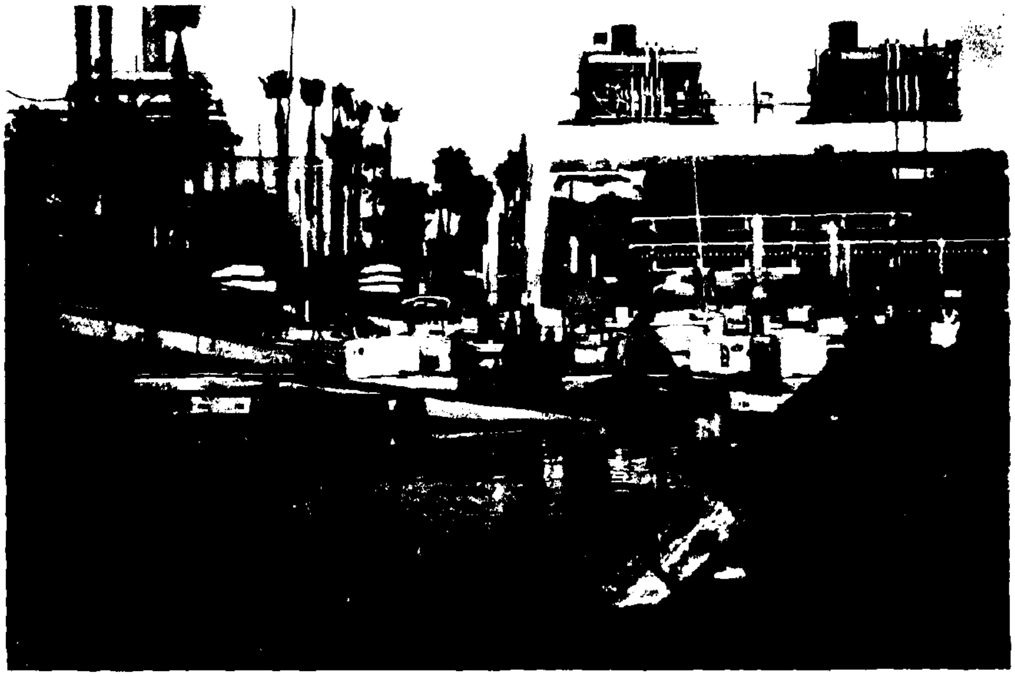


FIGURE 2-8 Tilting of the Mooring Piles at the Top of the Rock Berm of the Pier in Redondo Beach

FIGURE 2-9 Liquefaction-induced Settlement of a Building on the Pier in Redondo Beach

FIGURE 2-10 Rock Slides in the Region North of the Epicenter

FIGURE 2-11 Landslides in Santa Monica Along Pacific Coast Highway

a major slide occurred in a slope built with the tailings from a mining operation. Figure 2-12 shows the failed slope where lateral and vertical permanent deformations were as large as one and two meters, respectively. A survey of the slope region revealed that water used in the mining operation is directed through trenches away from the top of the slope towards its toe. The failed slope was observed to be free of ground water. Geotechnical investigations, including analysis of the strength properties of the tailing, may lead to definitive reasons for this failure.

In Granada Hills, on Balboa Boulevard, immediately north of State Route 118, there was evidence of significant permanent ground deformation. About three blocks along this street, and on one block on each side of the street, there were many cracks in the ground running perpendicular to Balboa Boulevard. Some of these were tensile cracks with widths as large as six to ten inches, as shown in Figure 2-13. Other cracks were of the compressive type, resulting in ridges in the sidewalks, as shown in Figure 2-14. In this section of Balboa Boulevard, there were many ruptures of gas lines leading to fires that destroyed nearby houses. Also, the water main (Figure 2-15) in this same section ruptured causing major floods. The cause of these ground fissures is not yet well understood. Since the fault in this region is closer to the surface than anywhere else in the San Fernando Valley, it is possible that the ground deformation in this region resulted from fault rupture. Alternatively, since the cracks in the ground are limited to the section of Balboa Boulevard that is on a hill, shallow slope failures, where blocks of soil moved downhill and relative to one another, cannot be ruled out as a reason for these cracks.

In summary, evidence indicates that geotechnical factors played an important role during the Northridge earthquake. Understanding of the various geotechnical aspects of this earthquake will require analysis using site specific geologic and geotechnical information and a systematic research effort to this end is strongly recommended.

2.5 Strong Ground Motion

Strong-motion recordings were obtained from three accelerograph networks with significant instrument arrays in the Southern California region. The California Division of Mines and Geology's Strong Motion Instrumentation Program (CSMIP) recovered 193 accelerograms from their network, the U.S. Geological Survey's National Strong Motion Program (NSMP) recovered approximately 150 accelerograms from their network, and the University of Southern California's Los Angeles Strong Motion Accelerograph Network (USC) recovered 65 accelerograms from their network, for a total of 408 recordings. A listing of peak accelerations from the CSMIP [3] and USGS/NSMP [4] networks are listed in Appendices A and B. No such listing is yet available for the USC accelerograph network.

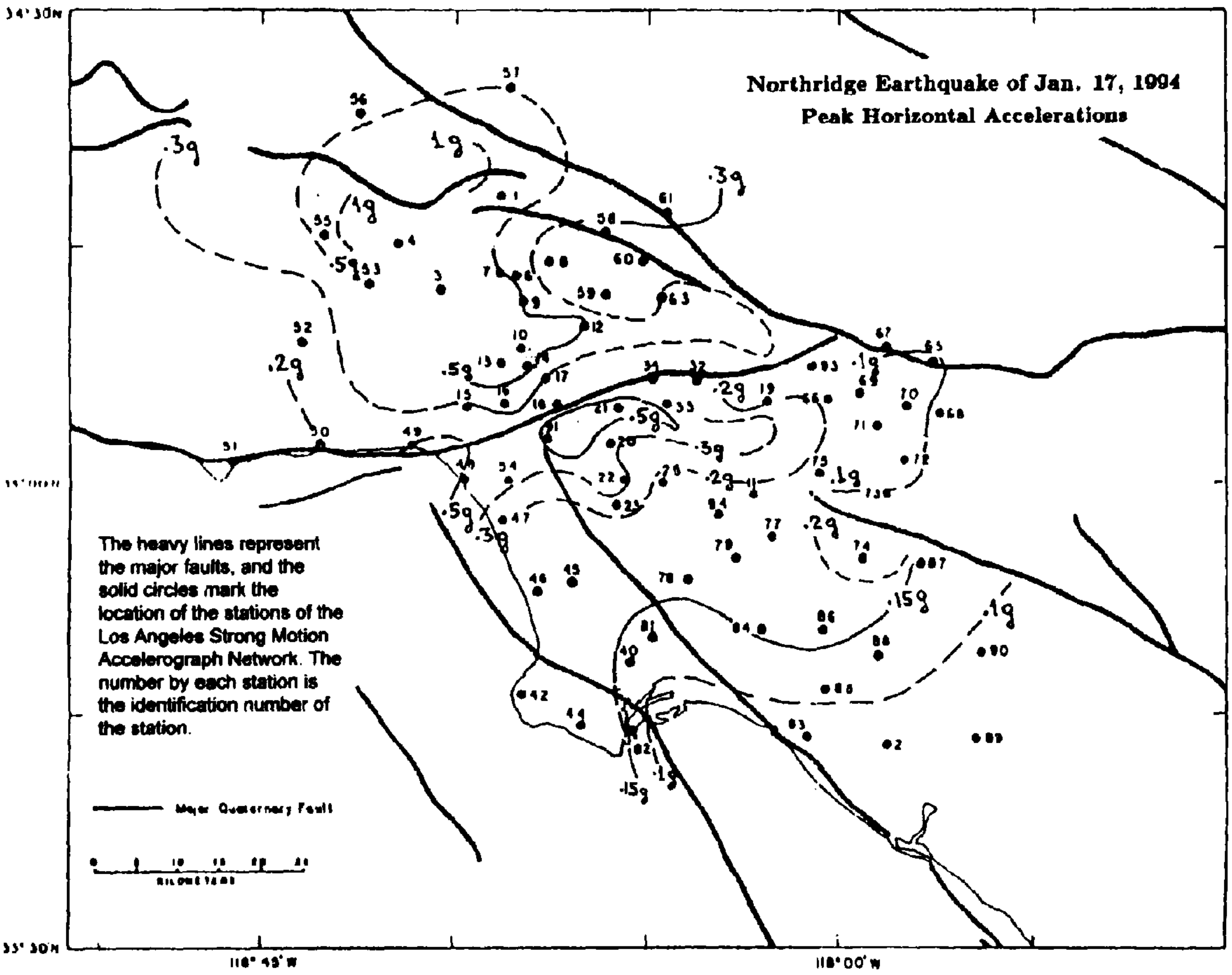
A contour map of the maximum component of peak horizontal acceleration for the San Fernando Valley and Los Angeles Basin developed by Todorovska and others [5] is shown in Figure 2-16. A similar map for the vertical component is shown in Figure 2-17. These maps were constructed

FIGURE 2-12 Slope Failure in Simi Valley at a Rock Quarry

FIGURE 2-13 Ground Fissures Along Balboa Boulevard in Granada Hills

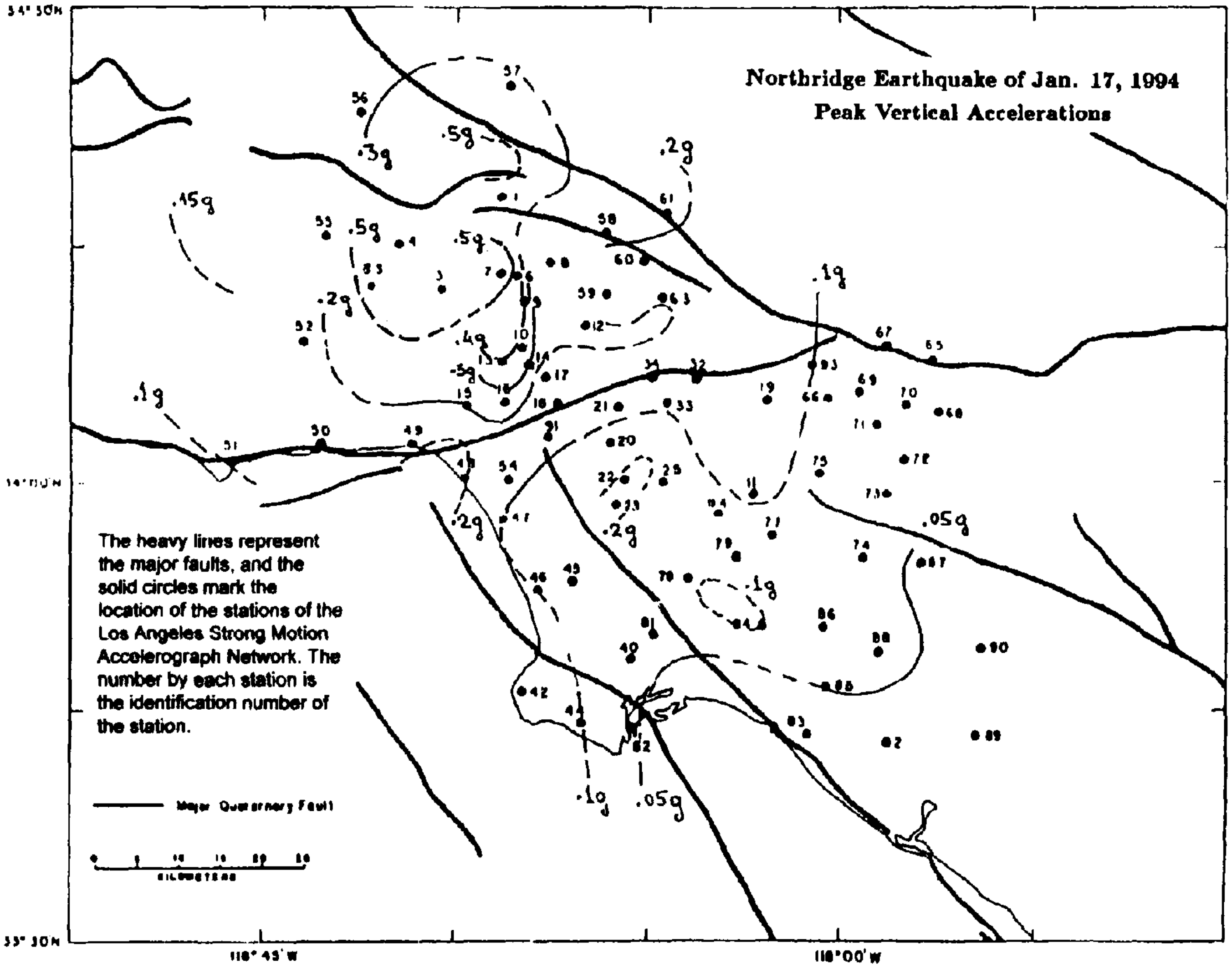
FIGURE 2-14 Compressive Ground Deformation Along Balboa Boulevard in Granada Hills

FIGURE 2-15 Section of the Water Main Along Balboa Boulevard that had to be Repaired After the Earthquake



The heavy lines represent the major faults, and the solid circles mark the location of the stations of the Los Angeles Strong Motion Accelerograph Network. The number by each station is the identification number of the station.

FIGURE 2-16 Contours of Peak Horizontal Ground Acceleration Observed During the Northridge Earthquake Expressed as a Fraction of the Acceleration of Gravity (as of February 1, 1994)



The heavy lines represent the major faults, and the solid circles mark the location of the stations of the Los Angeles Strong Motion Accelerograph Network. The number by each station is the identification number of the station.

FIGURE 2-17 Contours of Peak Vertical Ground Acceleration Observed During the Northridge Earthquake Expressed as a Fraction of the Acceleration of Gravity (as of February 1, 1994).

from the USC data and from CSMIP and USGS/NSMP recordings that were available as of February 1. These figures indicate that most of the central and eastern San Fernando Valley and the Santa Clarita Valley experienced maximum horizontal and vertical accelerations in excess of 0.5g. Maximum horizontal accelerations approaching or exceeding 1g were observed at a few stations in the northern part of the San Fernando Valley and at the CSMIP Tarzana site (see Figure 2-4) located 5km from the epicenter at the base of the Santa Monica Mountains in the southern San Fernando Valley.

Maximum horizontal accelerations exceeding 0.5g were also observed immediately south of the Santa Monica Mountains in the Santa Monica and West Hollywood areas. In contrast, these areas experienced relatively low vertical accelerations with values generally less than about 0.2g. The accelerations attenuated rapidly southeast of these areas as the seismic waves propagated into the Los Angeles basin. Downtown Los Angeles experienced maximum horizontal accelerations of about 0.2 to 0.3g. The central and eastern sections of the basin saw maximum horizontal accelerations of between 0.1 and 0.2g.

All three components of the Tarzana recording had peak accelerations exceeding 1g, the largest being 1.82g on the east-west component. This is in stark contrast to the small amount of damage that was observed in the immediate vicinity of the site, which was consistent with a Modified Mercalli Intensity (MMI) of VIII (J. Dewey, written communication, 1994). Although response spectra are not yet available for this recording, an accelerogram obtained at this site during the 1987 Whittier Narrows earthquake indicated that the recording site was subject to strong resonance at a frequency of about 3Hz during that event [6]. This resonance resulted in a maximum horizontal acceleration of 0.62g, although the station was 44km from the epicenter, rivaling that recorded in the epicentral region.

There was some concern immediately after the earthquake that unusually large vertical accelerations had been recorded. This resulted from the observation that the CSMIP Arleta station, one of the first sites from which an accelerogram was retrieved after the earthquake, had a vertical acceleration (0.59g) that greatly exceeded that of the maximum horizontal component (0.35g). However, as more accelerograms were recovered, it became apparent that this observation was the result of an unusually low horizontal acceleration at this site rather than an unusually large vertical acceleration. Typically, peak vertical accelerations were found to be about two-thirds of the maximum horizontal acceleration (see Figure 2-18). Only at a few stations did the peak vertical acceleration nearly equal or exceed the maximum horizontal component.

As of March 5, only five CSMIP accelerograms had been digitized and processed [7]. The corrected accelerations, velocities, displacements and pseudo-velocity response spectra from these stations are reproduced in Figures 2-19 through 2-28. These recordings indicate that the

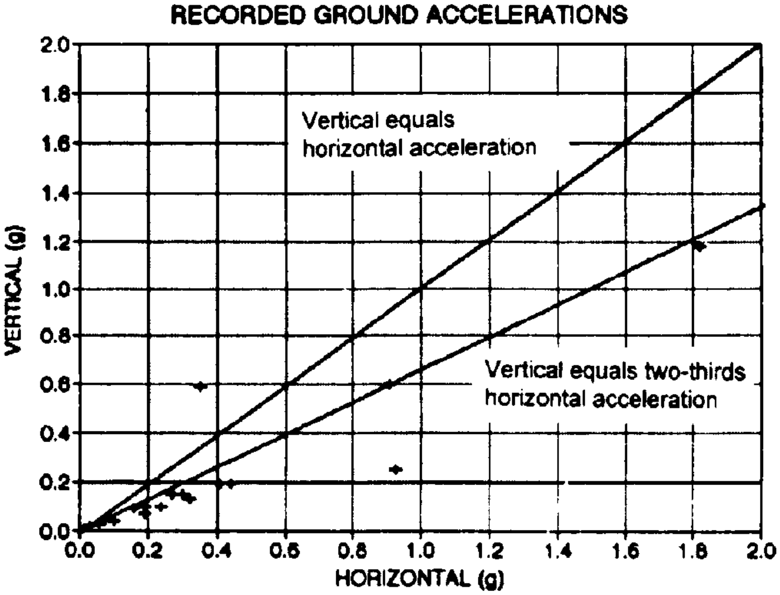


FIGURE 2-18 Peak Ground Accelerations Recorded by CSMIP Network

duration of significant shaking lasted for approximately 10 seconds or less in the epicentral region.

Except for the Santa Monica recording, the response spectra are typical of those observed during past earthquakes. The east-west spectral component of the Santa Monica recording (Figure 2-28), however, demonstrates a clear bimodal response at periods of about 0.2 to 0.3 seconds and two to three seconds that is not observed in the spectra from other stations. Inspection of the time series (Figure 2-27) indicates that this response is dominated by a large high-frequency pulse at about ten seconds, followed by a large low-frequency pulse at about 11 to 12 seconds. These pulses are either missing or substantially subdued on the north-south component. This behavior is probably a source and/or propagation effect, but further study will be necessary to confirm this conclusion.

It became apparent immediately after the earthquake that the recorded accelerations were higher than average for a magnitude 6.7 earthquake. To confirm this, selected peak horizontal accelerations that were available within a few weeks after the earthquake were compared to predictions for a reverse- or thrust-mechanism earthquake based on an attenuation relationship developed by Campbell and Bozorgnia [8] that had been published as a preprint about three months prior to the earthquake. This comparison is shown in Figures 2-29 through 2-31 for recordings on alluvium, soft rock and hard rock, respectively.

In all cases, the observed mean peak horizontal accelerations are found to plot between about the 50th-percentile (median) and the 98th-percentile (median plus two standard deviation) predictions, indicating above-average accelerations for earthquakes of similar mechanism. Similar results were obtained when comparisons were made with the attenuation relationships of Sadigh and others [9] and Boore and others [10], for which only the alluvium comparisons are shown in Figures 2-32 and 2-33. It is worth noting that similarly high accelerations were observed during the 1987 Whittier Narrows earthquake (e.g., [6]), suggesting that shallow-dipping blind thrust faults in the Los Angeles area may produce average ground motions higher than either strike-slip or more steeply dipping reverse faults in the region.

Preliminary contours of MMI developed by J. Dewey (written communication, 1994) and his colleagues at the USGS National Earthquake Information Center (NEIC) show a geographical distribution remarkably similar to that found for maximum horizontal acceleration (compare Figures 2-16 and 2-34). Based on their interpretation, pockets of intensity IX occurred throughout the western San Fernando Valley and the Santa Clarita Valley, and isolated reports of IX were observed in the Santa Monica, West Los Angeles and West Hollywood areas. Intensity VIII was observed throughout the epicentral region and along the southern margins of the Santa Monica Mountains. Intensity VII extended as far east as Fillmore, as far west as Glendale, and as far southeast as Los Angeles.

Although their geographic distributions are similar, the assigned values of MMI for this earthquake appear to be low relative to the recorded peak horizontal accelerations, at least when compared to predictions based on relationships previously developed between these two parameters (e.g., [11]). Preliminary estimates indicate that the reported intensities are approximately a unit lower than those predicted from these relationships. A similar observation was made after the 1987 Whittier Narrows earthquake [12]. It is interesting to note that both of these earthquakes had relatively high accelerations and relatively short durations as compared to earthquakes of similar magnitude, suggesting that MMI, and thus damage, may correlate more closely with the amount of energy released rather than with peak acceleration. Of course, it is also possible that a systematic bias towards lower intensities (less observed damage) has occurred over time as construction practices have improved and retrofit programs have been implemented.

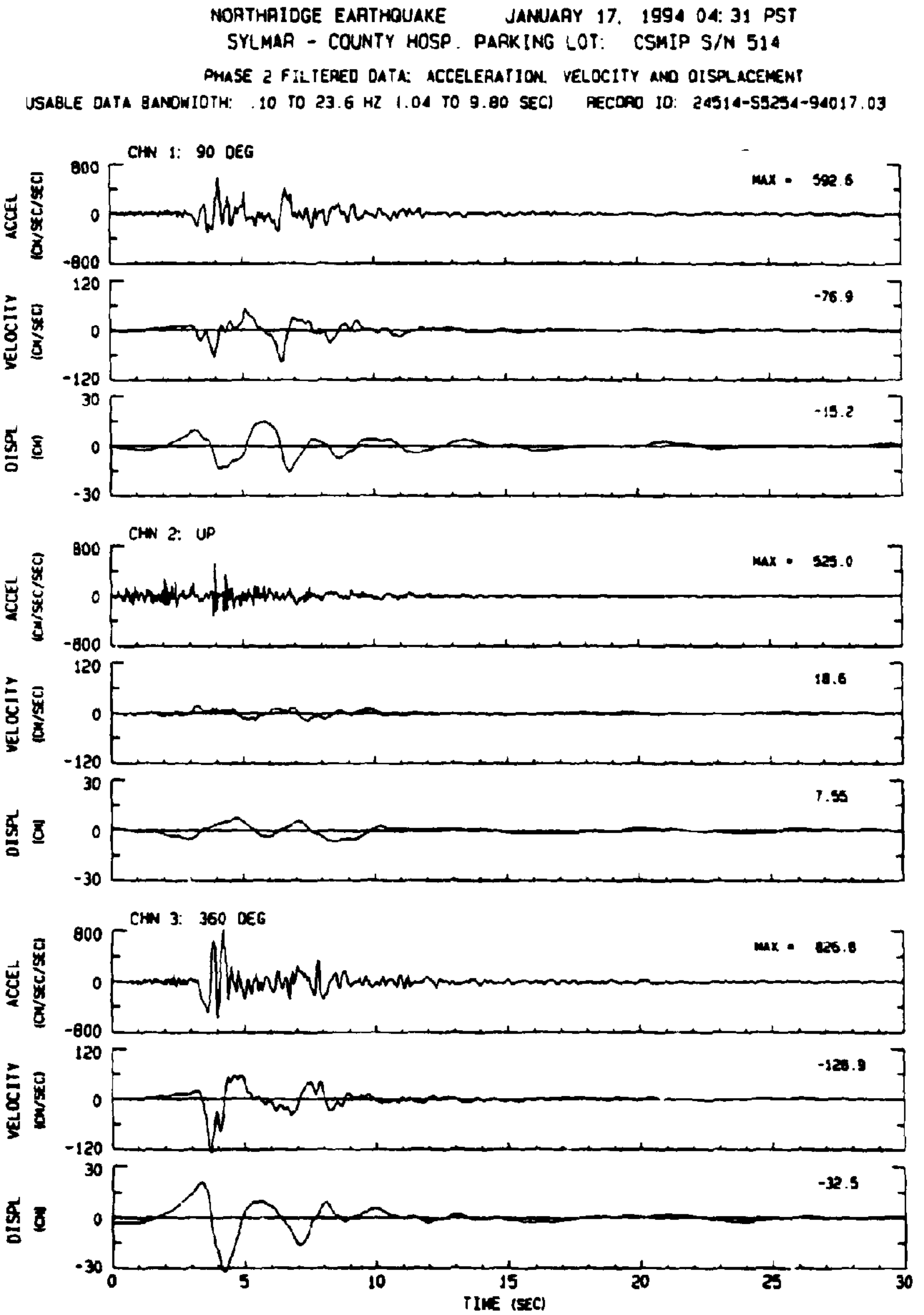
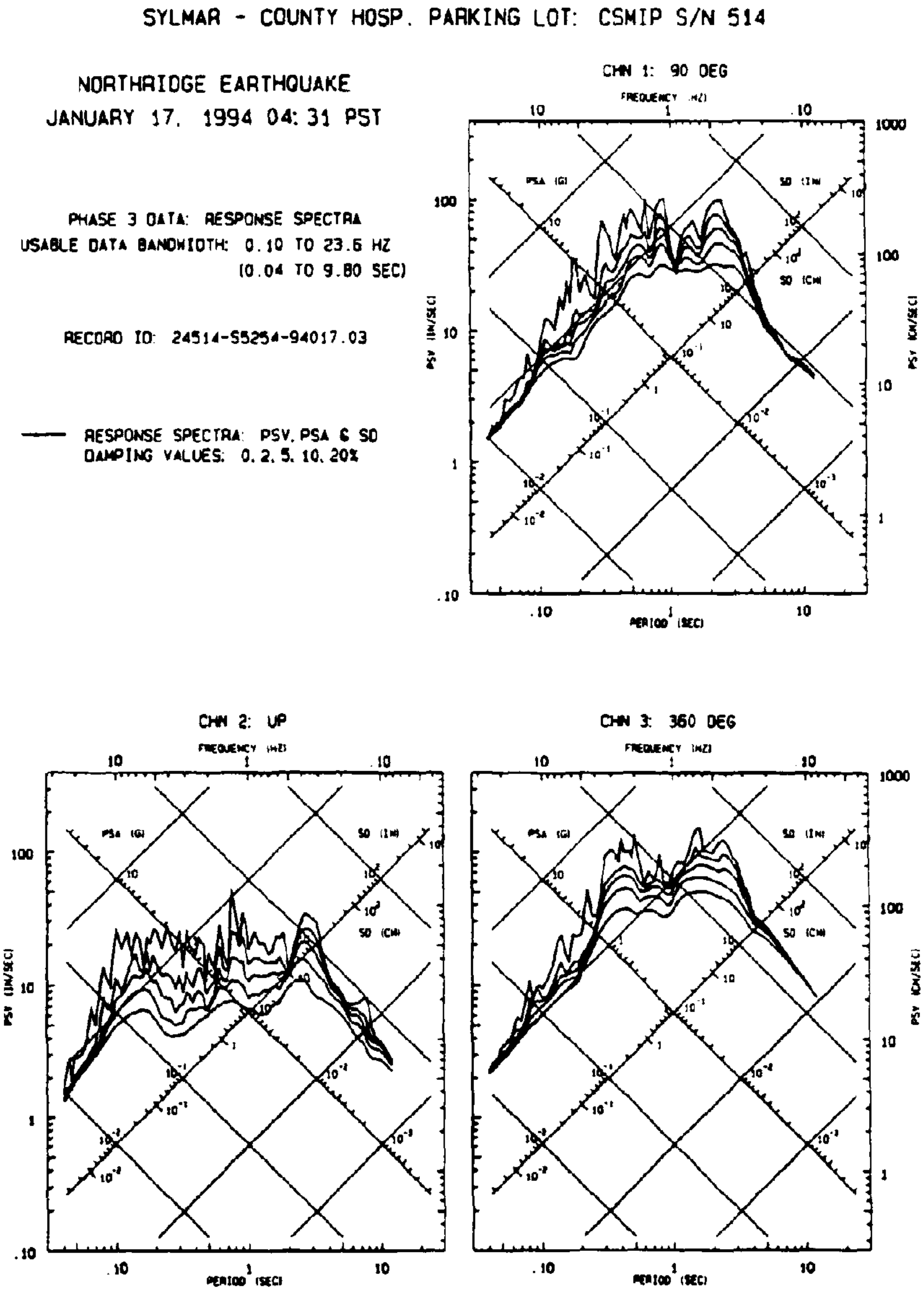


FIGURE 2-19 Corrected Acceleration, Velocity and Displacement Records from the CSMIP Sylmar - County Hospital Parking Lot Accelerograph Site [7]



SYLMAR - COUNTY HOSP. PARKING LOT: CSMIP S/N 514

NORTHRIDGE EARTHQUAKE
JANUARY 17, 1994 04:31 PST

PHASE 3 DATA: RESPONSE SPECTRA
USABLE DATA BANDWIDTH: 0.10 TO 23.6 HZ
(0.04 TO 9.80 SEC)

RECORD ID: 24514-S5254-94017.03

—— RESPONSE SPECTRA: PSV, PSA & SD
DAMPING VALUES: 0, 2, 5, 10, 20%

FIGURE 2-20 Pseudo-velocity Response Spectra from the CSMIP Sylmar - County Hospital Parking Lot Accelerograph Site [7]

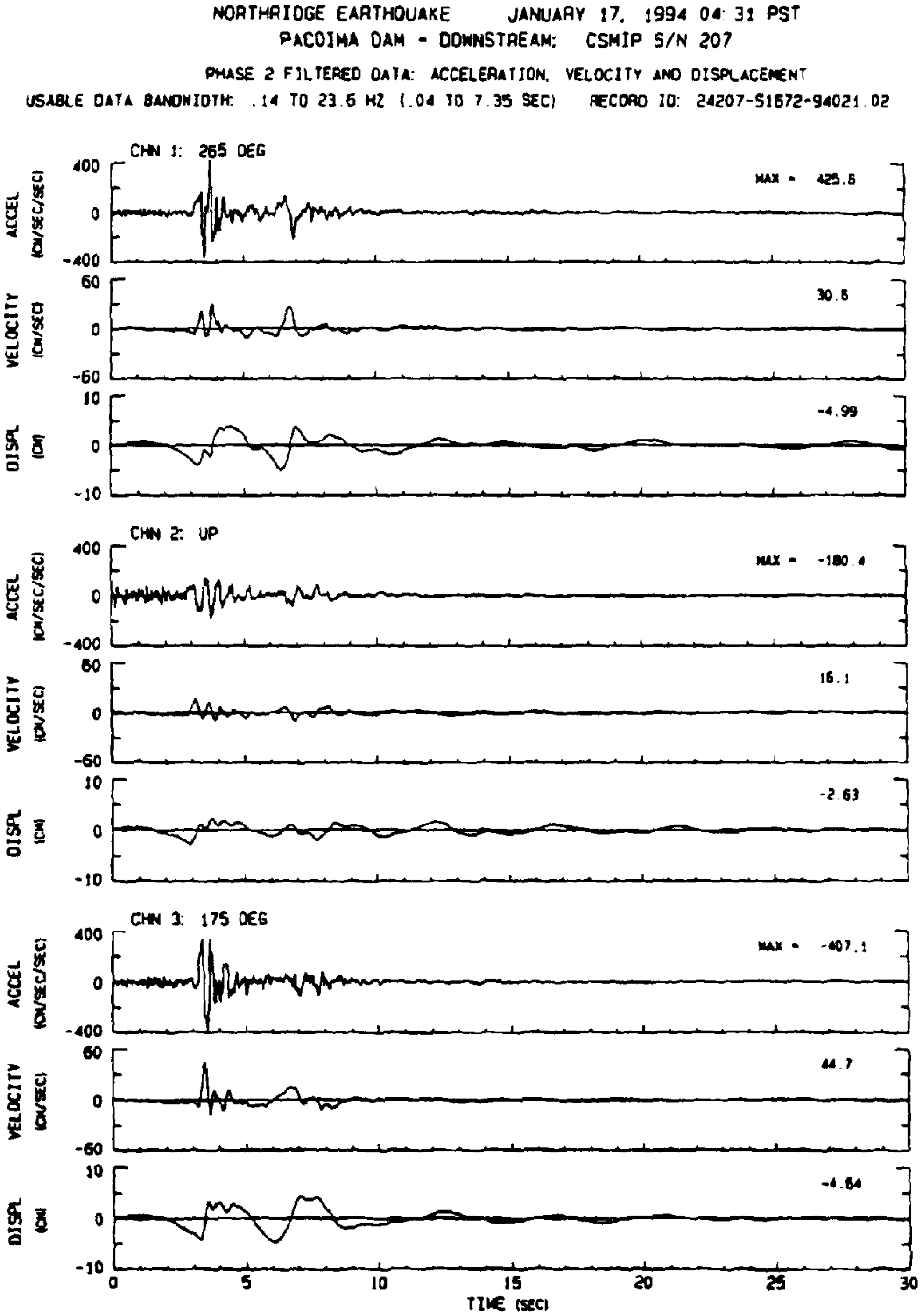


FIGURE 2-21 Corrected Acceleration, Velocity and Displacement Records from the CSMIP Pacoima Dam - Downstream Accelerograph Site [7]

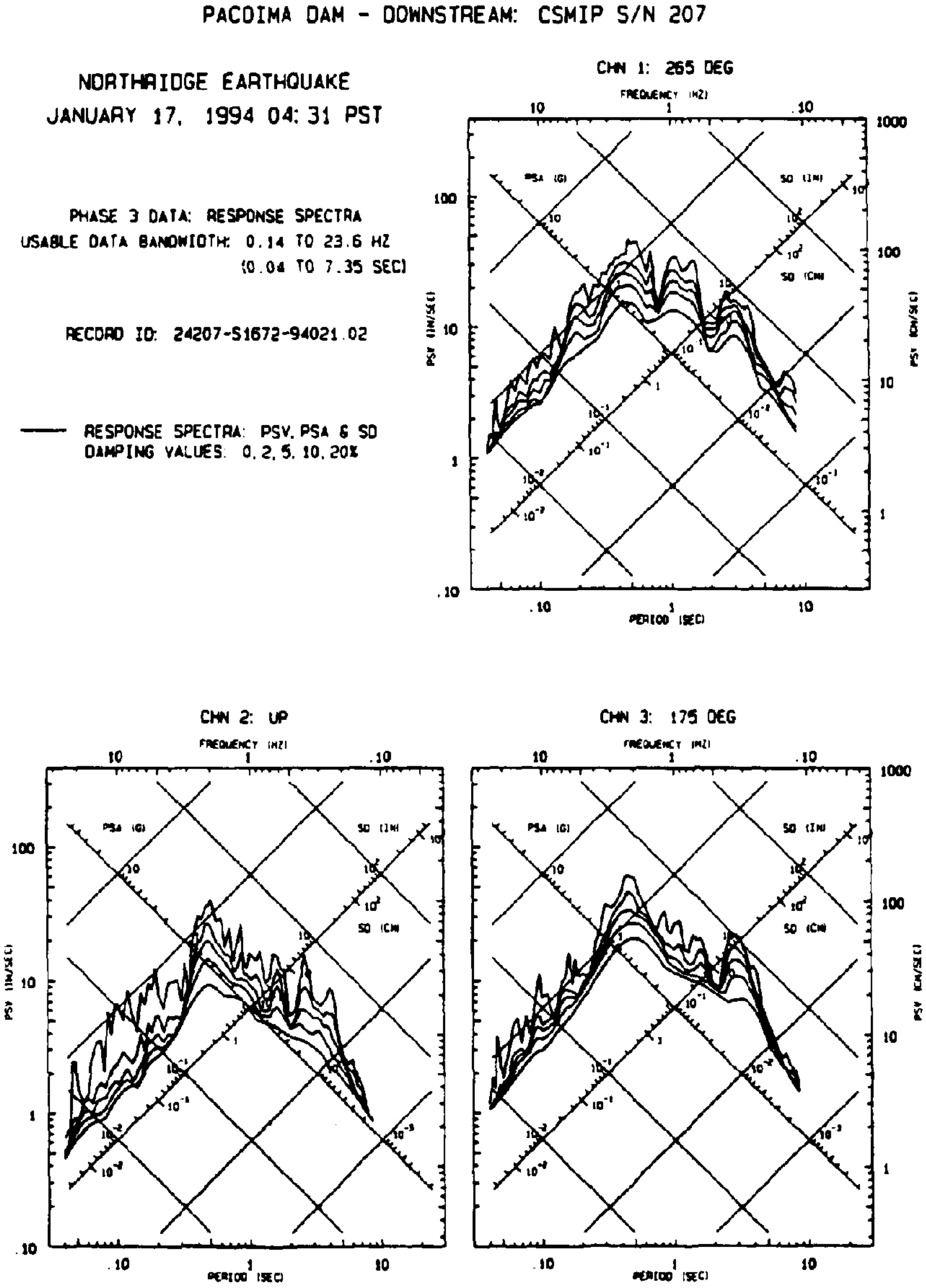


FIGURE 2-22 Pseudo-velocity Response Spectra from the CSMIP Pacoima Dam - Downstream Accelerograph Site [7]

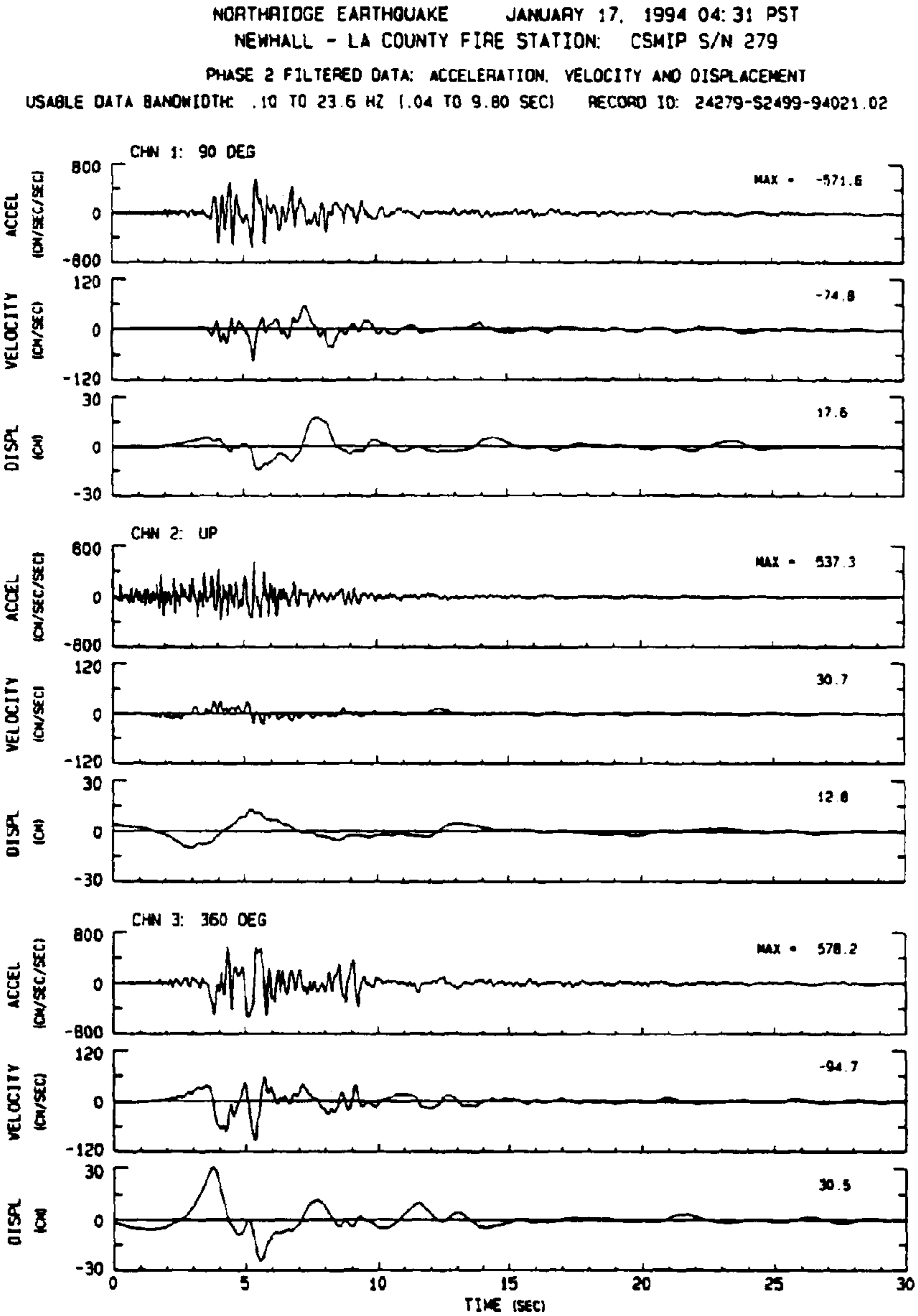


FIGURE 2-23 Corrected Acceleration, Velocity and Displacement Records from the CSMIP Newhall - LA County Fire Station Accelerograph Site [7]

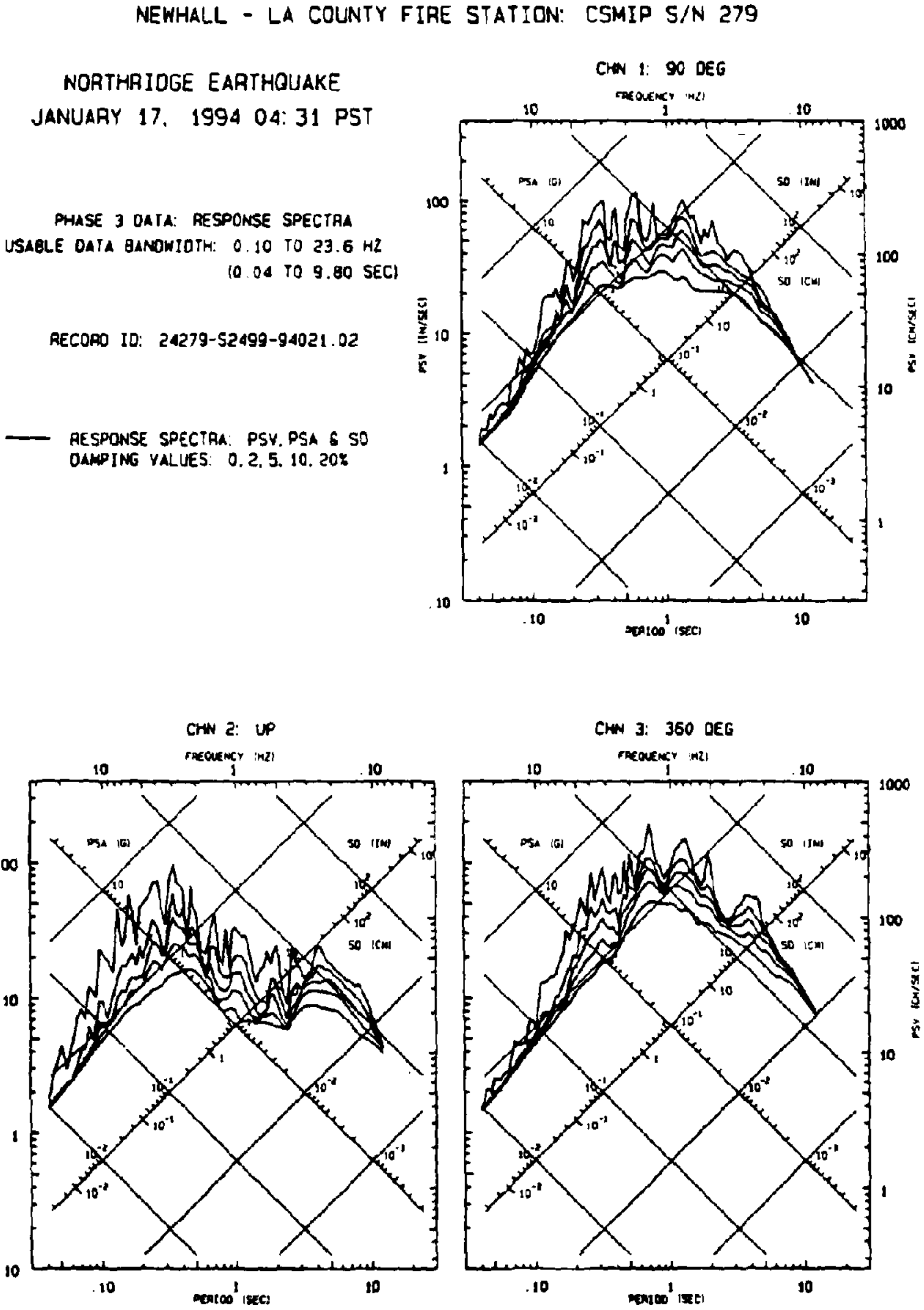


FIGURE 2-24 Pseudo-velocity Response Spectra from the CSMIP Newhall - LA County Fire Station Accelerograph Site [7]

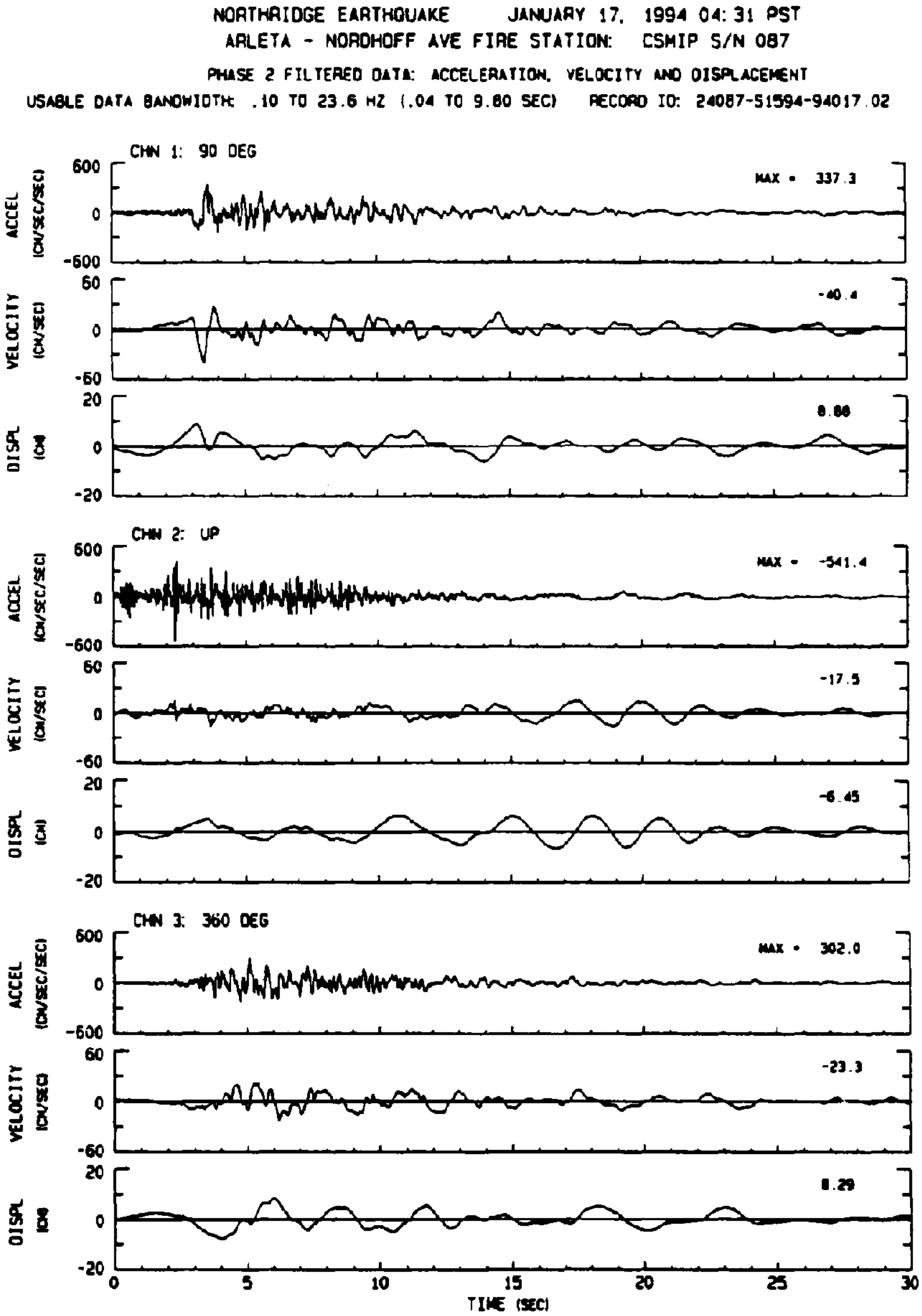
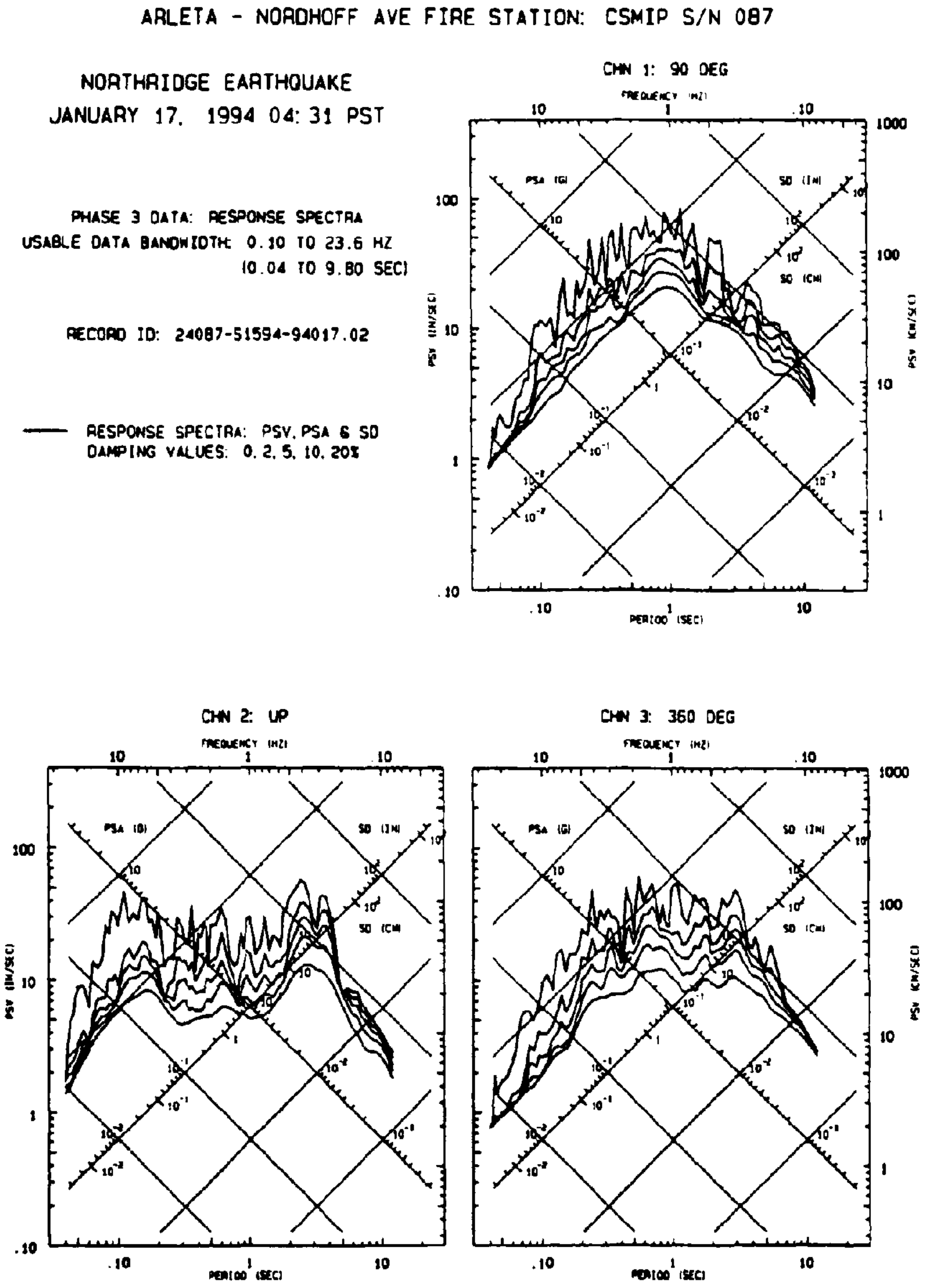


FIGURE 2-25 Corrected Acceleration, Velocity and Displacement Records from the CSMIP Arleta - Nordhoff Avenue Fire Station Accelerograph Site [7]



ARLETA - NORDHOFF AVE FIRE STATION: CSMIP S/N 087

NORTHRIDGE EARTHQUAKE
JANUARY 17, 1994 04:31 PST

PHASE 3 DATA: RESPONSE SPECTRA
USABLE DATA BANDWIDTH: 0.10 TO 23.6 HZ
(0.04 TO 9.80 SEC)

RECORD ID: 24087-51594-94017.02

RESPONSE SPECTRA: PSV, PSA & SD
DAMPING VALUES: 0, 2, 5, 10, 20%

FIGURE 2-26 Pseudo-velocity Response Spectra from the CSMIP Arleta - Nordhoff Avenue Fire Station Accelerograph Site [7]

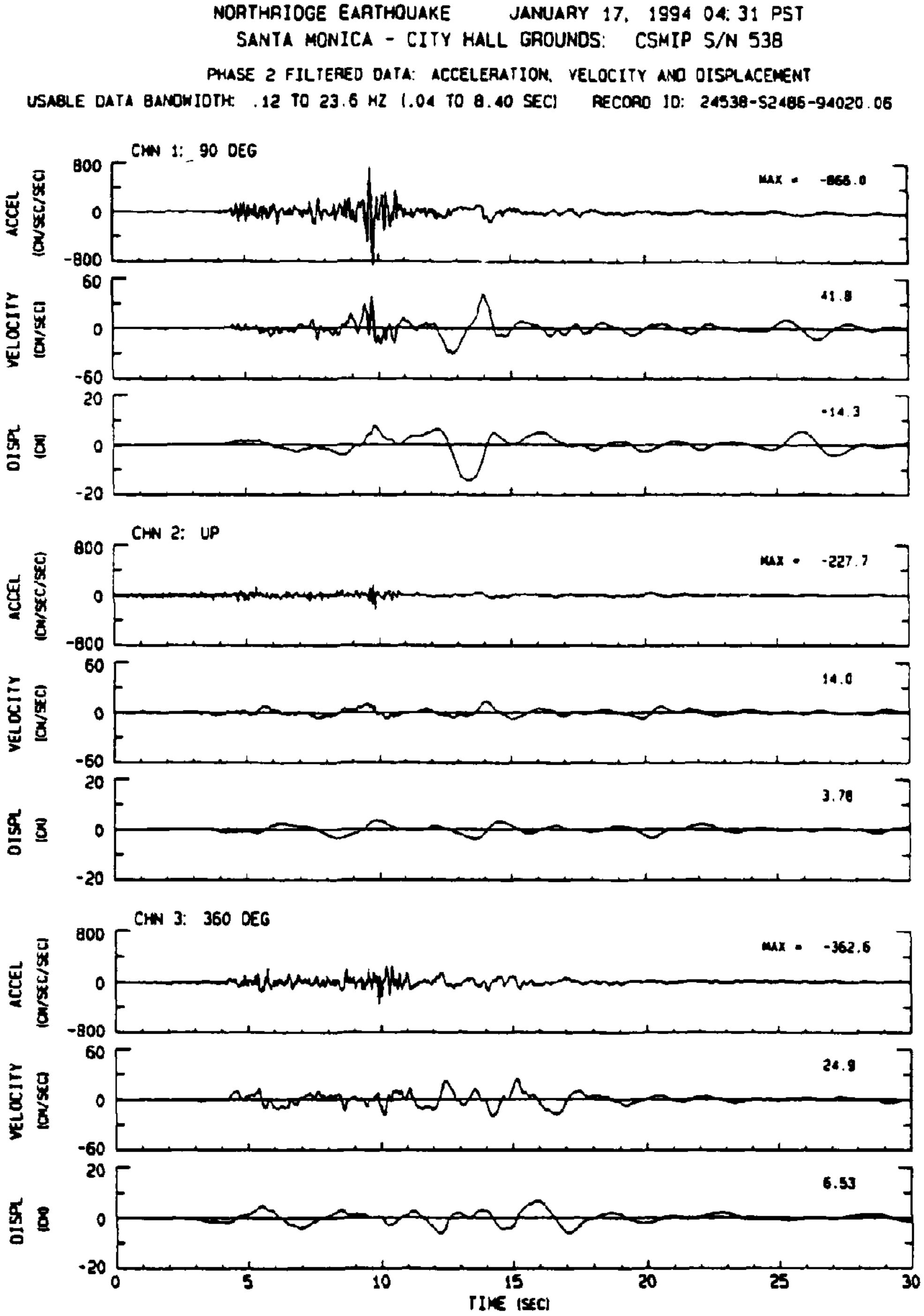


FIGURE 2-27 Corrected Acceleration, Velocity and Displacement Records from the CSMIP Santa Monica - City Hall Grounds Accelerograph Site [7]

SANTA MONICA - CITY HALL GROUNDS: CSMIP S/N 538

NORTHRIDGE EARTHQUAKE
JANUARY 17, 1994 04:31 PST

PHASE 3 DATA: RESPONSE SPECTRA
USABLE DATA BANDWIDTH: 0.12 TO 23.6 HZ
(0.04 TO 8.40 SEC)

RECORD ID: 24538-S2486-94020.06

—— RESPONSE SPECTRA: PSV, PSA & SD
DAMPING VALUES: 0, 2, 5, 10, 20%

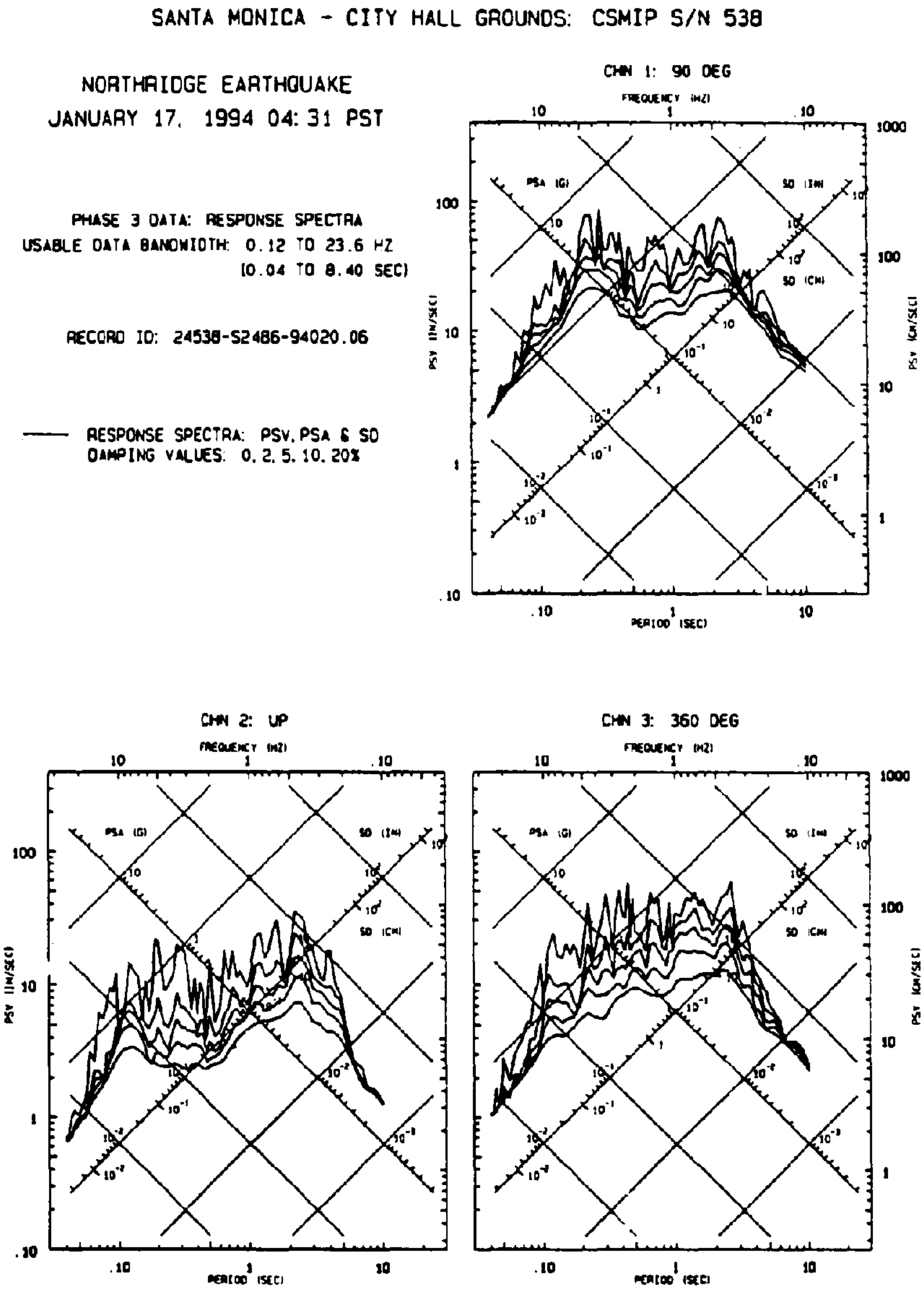


FIGURE 2-28 Pseudo-velocity Response Spectra from the CSMIP Santa Monica - City Hall Grounds Accelerograph Site [7]

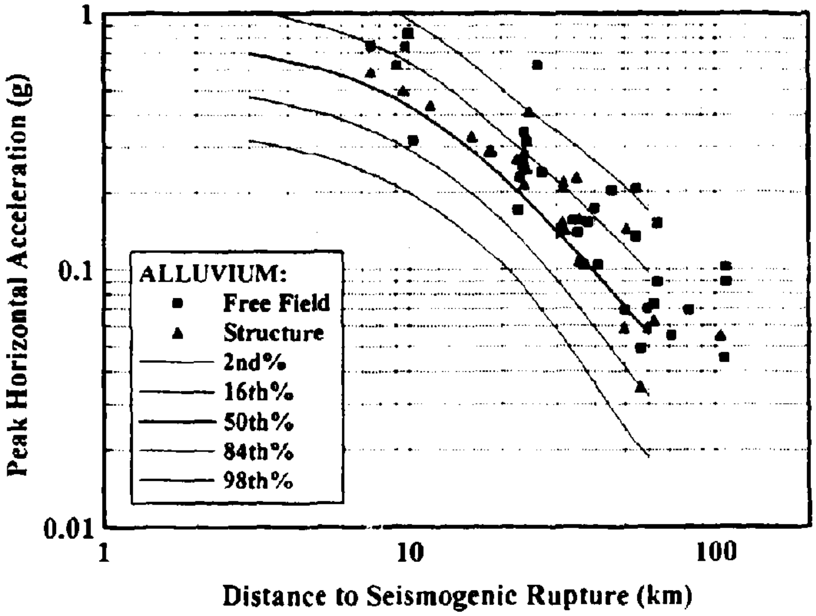


FIGURE 2-29 Comparison of Selected Recordings of Mean Peak Horizontal Acceleration on Alluvium with Predictions Based on the Attenuation Relationship Developed by Campbell and Bozorgnia [8]

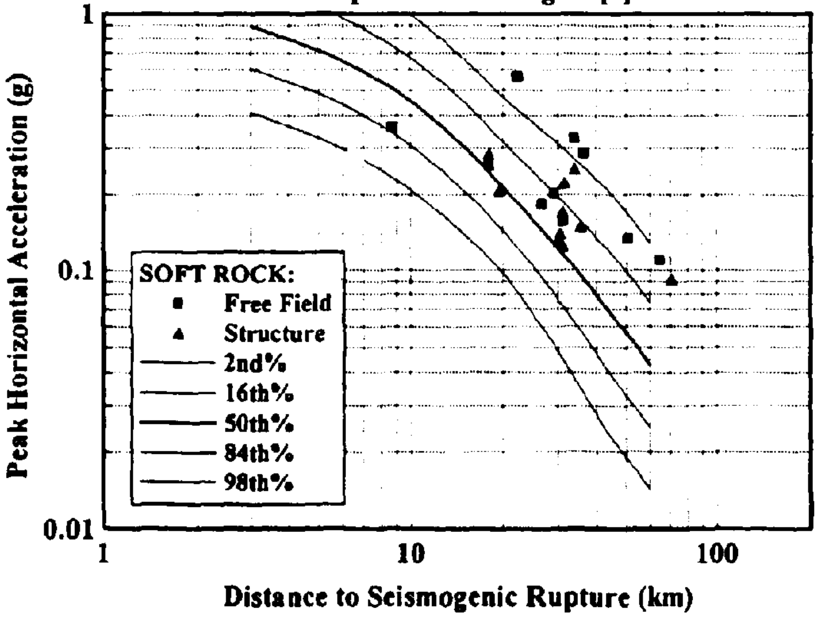


FIGURE 2-30 Comparison of Selected Recordings of Mean Peak Horizontal Acceleration on Soft Rock with Predictions Based on the Attenuation Relationship Developed by Campbell and Bozorgnia [8]

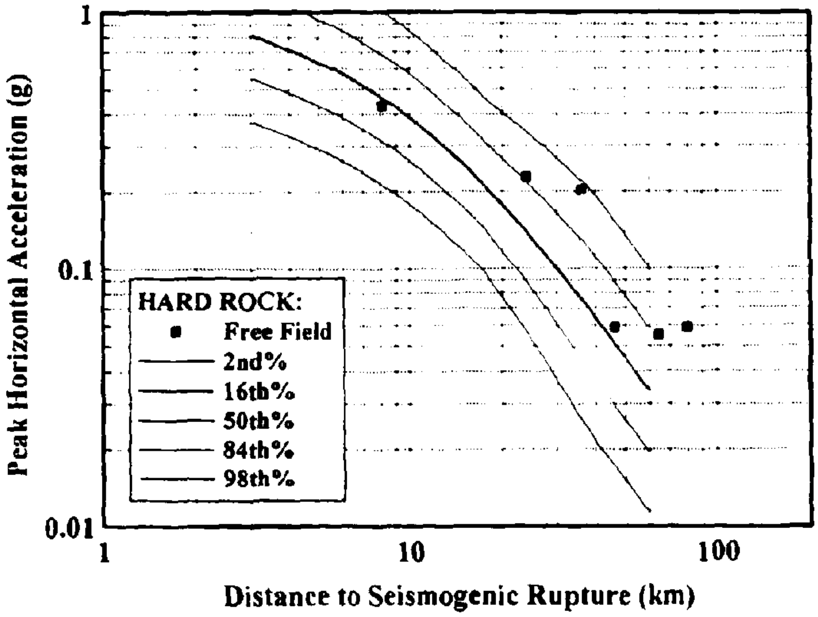


FIGURE 2-31 Comparison of Selected Recordings of Mean Peak Horizontal Acceleration on Hard Rock with Predictions Based on the Attenuation Relationship Developed by Campbell and Bozorgnia [8]

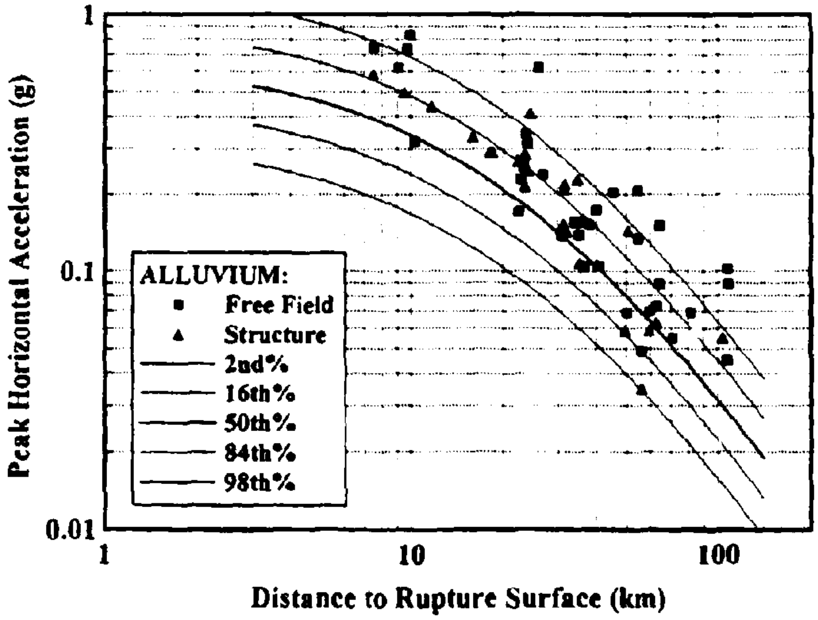


FIGURE 2-32 Comparison of Selected Recordings of Mean Peak Horizontal Acceleration on Alluvium with Predictions Based on the Attenuation Relationship Developed by Sadigh and others [9]

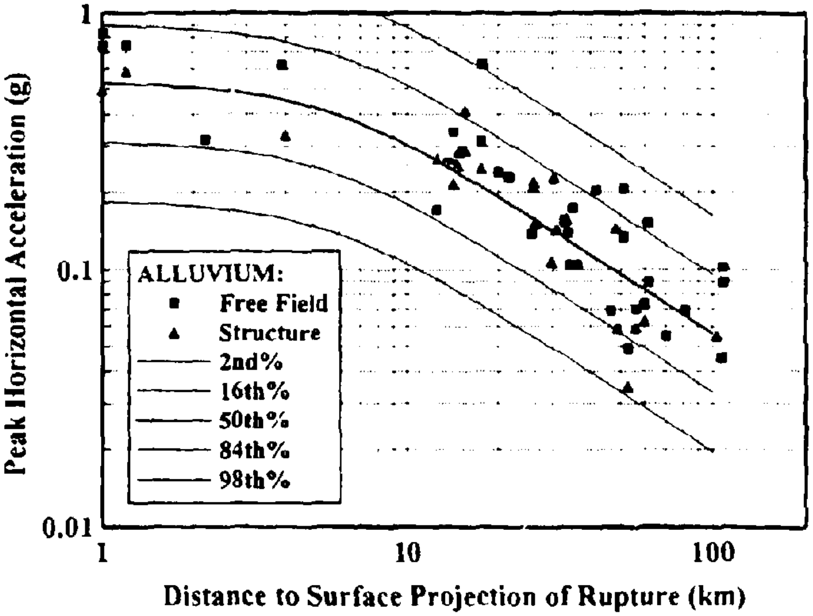


FIGURE 2-33 Comparison of Selected Recordings of Mean Peak Horizontal Acceleration on Alluvium with Predictions Based on the Attenuation Relationship Developed by Boore and Others [10]

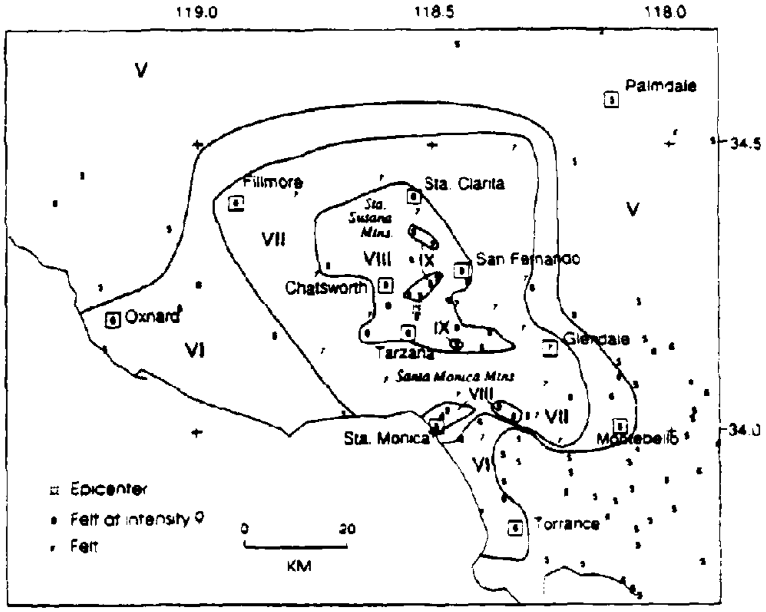


FIGURE 2-34 Contours of Modified Mercalli Intensity (MMI) Observed During the Northridge Earthquake (J. Dewey, written communication, 1994)

SECTION 3
STRUCTURES

3.1 Highway Bridges

During the Northridge earthquake of January 17, seven highway bridges suffered partial collapses and another 170 bridges suffered damage ranging from minor cracking to the slumping of abutment fills. Many of the damaged structures were closed only temporarily for inspection and/or shoring but some were closed permanently and have since been demolished pending replacement. Of those bridges with collapsed spans, all were designed and constructed from the mid-sixties to the mid-seventies. None were "new" in the sense of being built to current codes. Most had been retrofitted with cable restrainers, where appropriate. Some bridge columns in the epicentral region had also been strengthened with steel-jackets. Whereas several cable restrainer units failed, none of the steel-jacketed columns showed distress despite strong ground shaking in some cases.

Figure 3-1 shows the location of bridges which suffered major damage relative to the epicenter of the earthquake in Northridge. Damage sustained by these bridges and others, can be summarized as follows:

- Abutment back-fill settlement and erosion
- Abutment and shear key damage
- Flexural failures in plastic hinges with inadequate confinement
- Pounding and unseating at hinge seats and girder supports
- Shear failures in short single columns, piers, multicolumn bents, columns with flares and other accidental restraints, and columns in skewed bridges

This section contains a brief summary of several bridges that suffered major damage. A detailed report of damage to bridges is contained in [13]. These bridges are as follows:

- Gavin Canyon Undercrossing
- State Route 14/I-5 Antelope Valley Interchange:
  Separation and Overhead (Southbound)
  North Connector Overcrossing
- State Route 118 San Fernando/Simi Valley Freeway:
  Bull Creek Canyon Channel Bridge
  Mission-Gothic Undercrossing
  Balboa Boulevard Overcrossing
- I-10 Santa Monica Freeway:
  Fairfax-Washington Undercrossing
  La Cienega-Venice Undercrossing

A complete listing of all damaged bridges is given in [13].

FIGURE 3-1 Location Map of Bridges with Major Damage

Gavin Canyon Undercrossing

This undercrossing carries the north- and southbound lanes of Interstate 5 over Gavin Canyon Road on two separate bridges. Both structures suffered failures due to total or partial loss of support at the expansion joint hinges. Unseating generally started at the acute corner of each supported span due to a counterclockwise rotation of the structural sections about a vertical axis (Figure 3-2).

The movement of the superstructure caused restrainer cables to be pulled at an angle to their principal axis as evidenced by spalling at the edges of cored holes through which the restrainers passed. In some cases, restrainer cables snapped as the expansion joints separated while in other cases they pulled through the expansion joint diaphragm. Some cables remained intact, helping to support the partially unseated spans and preventing unseating of the span at one of the hinges.

Despite the strong ground shaking at the site, the structure suffered very little column damage. Only minor cracking was observed at the base of some columns. Cracked pavement at the bridge approaches is evidence that the fills shifted during the earthquake. There was some minor abutment damage. These observations are based on the reports of teams from Caltrans and the University of California at Berkeley who visited the site on January 17. Demolition of the unstable side spans began late on Monday, January 17 and much of the structural evidence had been removed by Tuesday, January 18.

State Route 14/I-5 Antelope Valley Interchange

Two of the five viaducts in this interchange (Figure 3-3) suffered partial collapse and a third sustained major abutment and hinge seat damage. Hinge restrainer and abutment shear keys were also damaged in the remaining two bridges but the level of damage was relatively minor. Many of these structures are shown in a general view of the interchange given in Figure 3-4. As described in [13], aftershock ground motions were recorded at this location for the purpose of studying spatial variation effects. Sites instrumented by the Lamont-Doherty Earth Observatory are shown in Figure 3-3. Data collected are discussed in [13].

The Southbound Separation and Overhead is a 10-span continuous, cast in place concrete box girder bridge, with slight curvature in plan. It was under construction at the time of the 1971 San Fernando earthquake and reconstruction appears to have been completed in 1974. In the present earthquake, the southernmost segment of the viaduct totally collapsed due, most probably, to a shear failure in a short squat end pier (pier 1) followed by shear failures in the superstructure at the face of the second pier (pier 2) and the unseating of the girder at both the abutment and hinge seat in span 3 (Figure 3-5). Seat widths for this bridge were smaller than those required by current Caltrans or American Association of State Highway and Transportation Officials (AASHTO) codes and cable restrainers had been fitted to address this deficiency. However, these restrainers were insufficient to prevent the unseating of the girders and most failed in direct

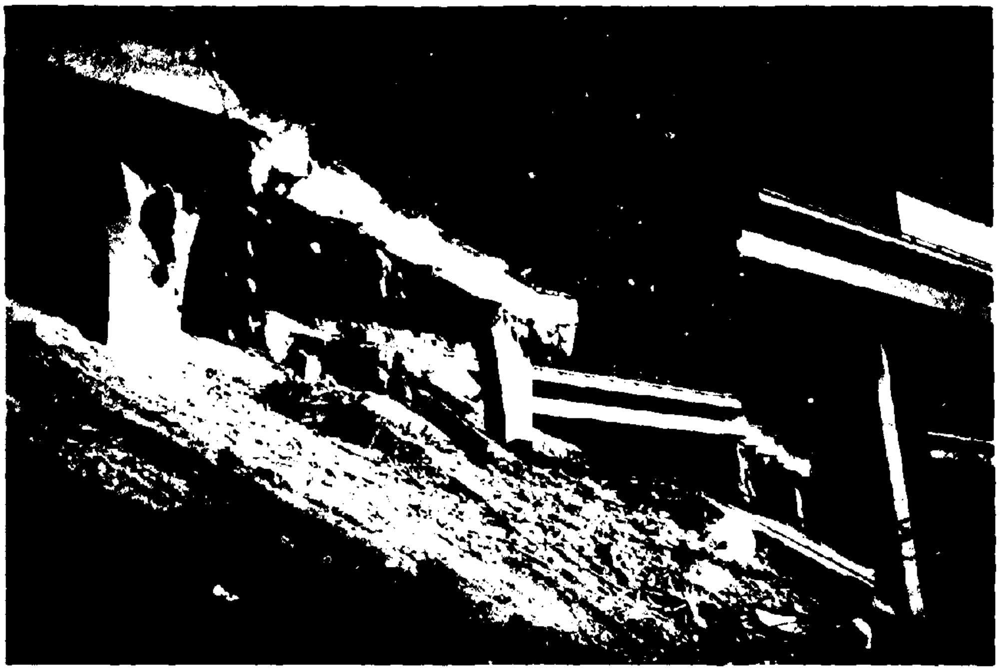


FIGURE 3-2 Gavin Canyon Undercrossing - Collapsed End Spans After Demolition

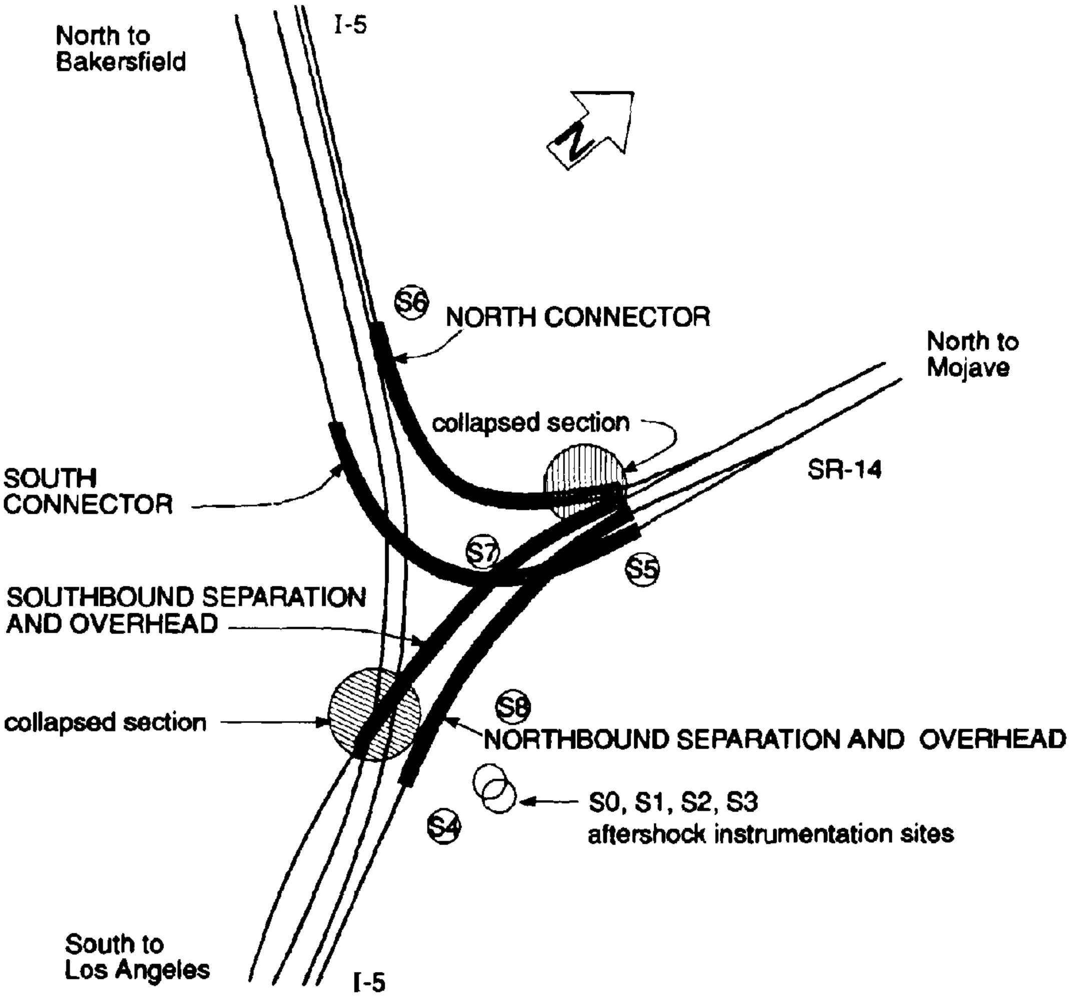


FIGURE 3-3 SR14/I-5 Interchange -
Simplified Plan and Locations of Sites where Aftershock Motion was Recorded

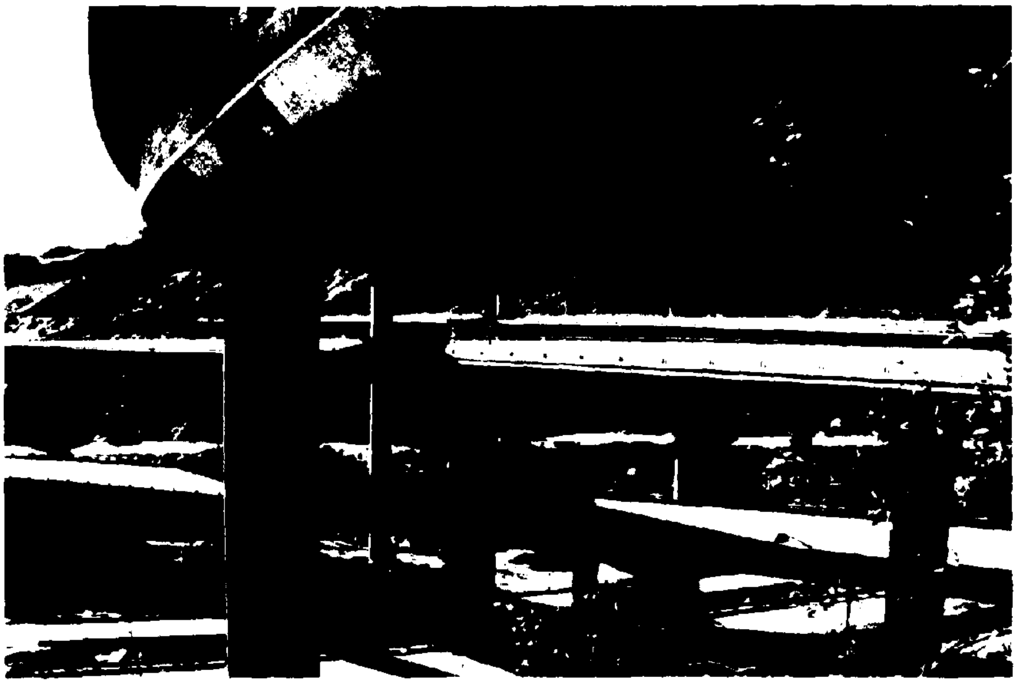


**FIGURE 3-4 SR14/I-5 Interchange -
General View from Abutment 10 of the South Connector Looking Southwest**

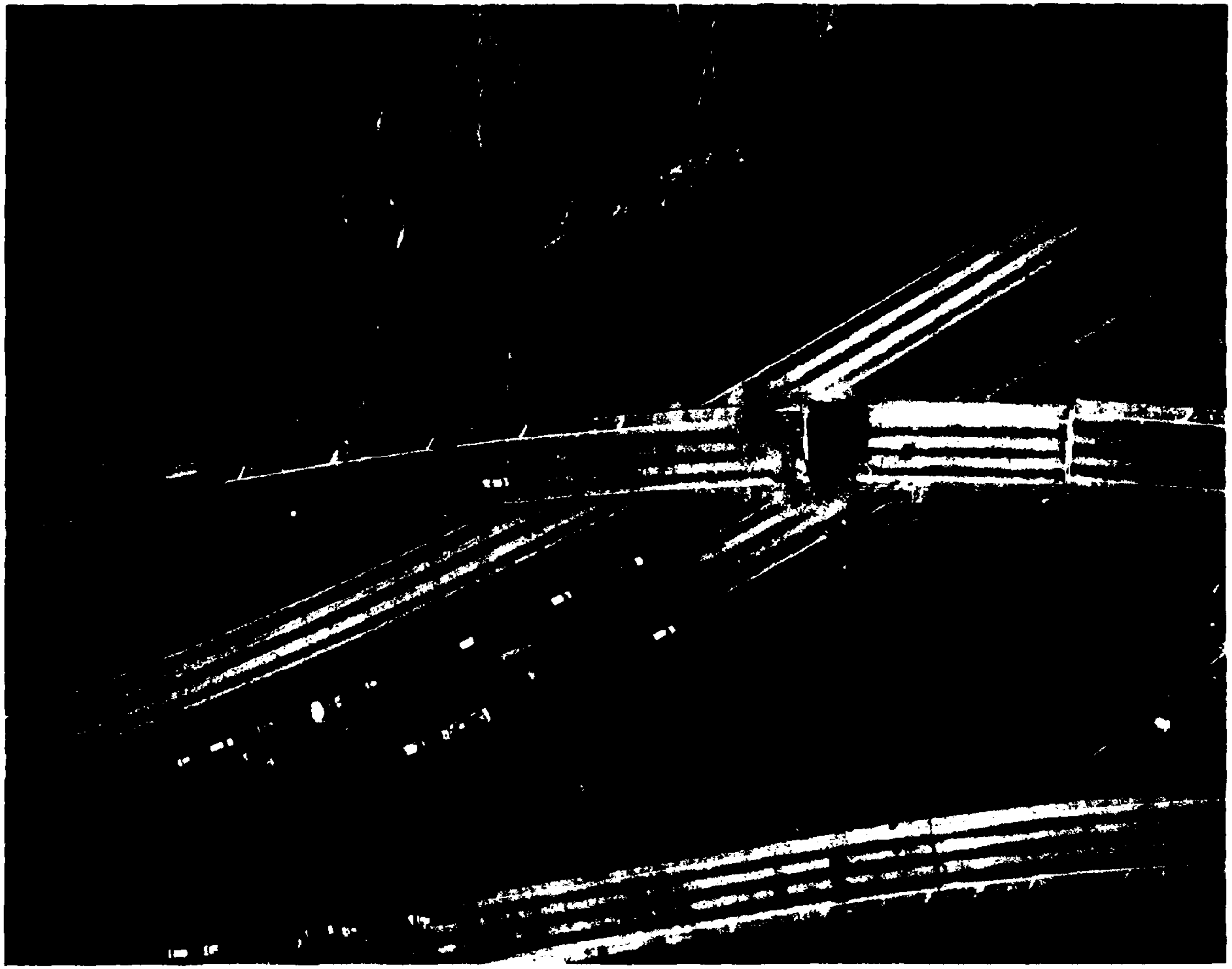


FIGURE 3-5 SR14/I-5 Separation and Overhead (Southbound) - Aerial View of Collapse

tension. The exact sequence of events leading to collapse is not clear at this time due to the uncertain effect of the curvature, the non-uniform distribution of bent stiffness (the short squat pier may have attracted an unacceptably high proportion of the base shear) and the nonlinearities introduced when the restrainers engaged and subsequently failed.

The North Connector is also a 10-span continuous, cast in place, concrete box girder bridge. Constructed in five segments, the total length is in excess of 1,500 feet with a radius of curvature of 550 feet. As with the Southbound Separation and Overhead, the southernmost end segment collapsed and again the sequence of collapse may have been the shear failure of a short squat end pier (pier 2) followed by shear failure of the superstructure at the face of pier 3 and unseating of the girder at the abutment (Figure 3-6). In the absence of rigorous analysis, the sequence of failure is uncertain but it is possible that pier 2 attracted a much higher proportion of the lateral load than assumed in design because of its relatively short height. Further, there was probably a significant reduction in the axial load in the pier due to both the severe curvature in the bridge and the high vertical accelerations in the ground motion. This reduction in axial load may have reduced the shear capacity of the column to less than the demand leading to the failure of the pier.

The South Connector is another multi-span highly curved viaduct and was the only completed structure in this interchange at the time of the 1971 San Fernando earthquake. Several spans collapsed during this earlier earthquake, and during reconstruction, larger hinge seats were provided and some column reinforcement details modified. In the present earthquake, none of the spans collapsed, but there was clear evidence of pounding at the hinge seats and major distress to the southern abutment (Figure 3-7). Demolition and replacement may be necessary.

State Route 118 San Fernando/Simi Valley Freeway

Three bridges on this freeway sustained major collapses and/or damage to their abutments. The Bull Creek Canyon Channel bridge is a three-span multi-cell box girder bridge carrying SR118 over a small drainage channel. Both multicolumn bents suffered hinge failures causing the superstructure to settle vertically with only slight translation horizontally (Figure 3-8). Each column in the eastern bent failed just above a training wall for the channel. This wall appeared to be structurally connected to each of the columns in the bent and most probably gave substantial restraint to these columns. This restraint was presumedly unintended and it led to premature shear failures in the columns due to the reduction in the clear height of these members. The western bent was not adjacent to the drainage channel and accidental restraint and premature shear failures did not appear to be present. Nevertheless, the flexural hinges that did occur, did so just below the termination of the spiral reinforcement at the top of each column indicating an inadequate length of this confining steel.

FIGURE 3-6 SR14/I-5 North Connector - Collapsed End Spans After Demolition

FIGURE 3-7 SR14/I-5 South Connector - Damage to Abutment 10

The Mission-Gothic Undercrossing has abutments on opposing 45° skew alignments and thus the length and number of spans differs between the eastbound and westbound structures. During the earthquake, the eastbound bridge sustained major damage to shear key and columns leading to the partial collapse of the eastern end span (Figure 3-9). It seems likely that the unusual skew geometry may have initiated this collapse. The non-uniform restraint of the abutment backfills may have permitted rotation of the bridge in plan. If so, this rotation would have been initially restrained by the abutment shear keys and the multicolumn bents. It seems likely that the abutment restraints immediately failed, leaving the columns to resist the lateral loads alone. However, the columns were flared from about their mid height to the top of the column. These flares are usually added for aesthetic reasons and not intended to add structural strength to the column. But in this case, unintended structural interaction between the column and the flare reduced the effective height of the column which in turn led to higher shear forces in the columns and to their subsequent failure immediately below the flare (Figure 3-10). These flares are a common feature of modern Caltrans bridges and their participation in the overall capacity of the column has been previously questioned. However, until now there has not been any field evidence of a problem with this detail.

The Balboa Boulevard Overcrossing is a two-span bridge carrying local traffic and numerous utility lines across SR118. During the earthquake, one or more water lines ruptured in or near the southern abutment, and the subsequent discharge of water eroded the fill from behind the abutment. Several 16-inch CIDH piles were exposed and structural damage, in the form of cracking, was also sustained by the abutment walls (Figure 3-11). The bridge was temporarily closed due to loss of access.

I-10 Santa Monica Freeway

Two overcrossings about a quarter-mile apart collapsed along one segment of this Freeway between the Harbor Freeway and the San Diego Freeway. The two bridges are the Fairfax-Washington Undercrossing and the La Cienega-Venice Undercrossing. Built in 1964, they predate the 1971 San Fernando earthquake which subsequently led to major revisions to the Caltrans design code. Both bridges comprise continuous box girder spans of total lengths between 650 and 850 feet. Skew angles vary from bent-to-bent and range up to 55°. Expansion joint restrainers had been fitted to both bridges in the mid-seventies. Since all the bents were of the multicolumn type, with between six and eight large diameter columns per bent, column strengthening had not begun on these bridges. (Caltrans has given higher priority for seismic retrofitting to bridges with single column bents). The failure of these columns in shear led to the collapse of several sections of the freeway (Figures 3-12 and 3-13). Based on column shear capacity calculations, the ground accelerations under these structures is estimated at between 0.25 and 0.3g. This figure agrees well with records from some nearby building sites where peak ground accelerations range from 0.29 to 0.33g. Vertical components range up to 0.22g.

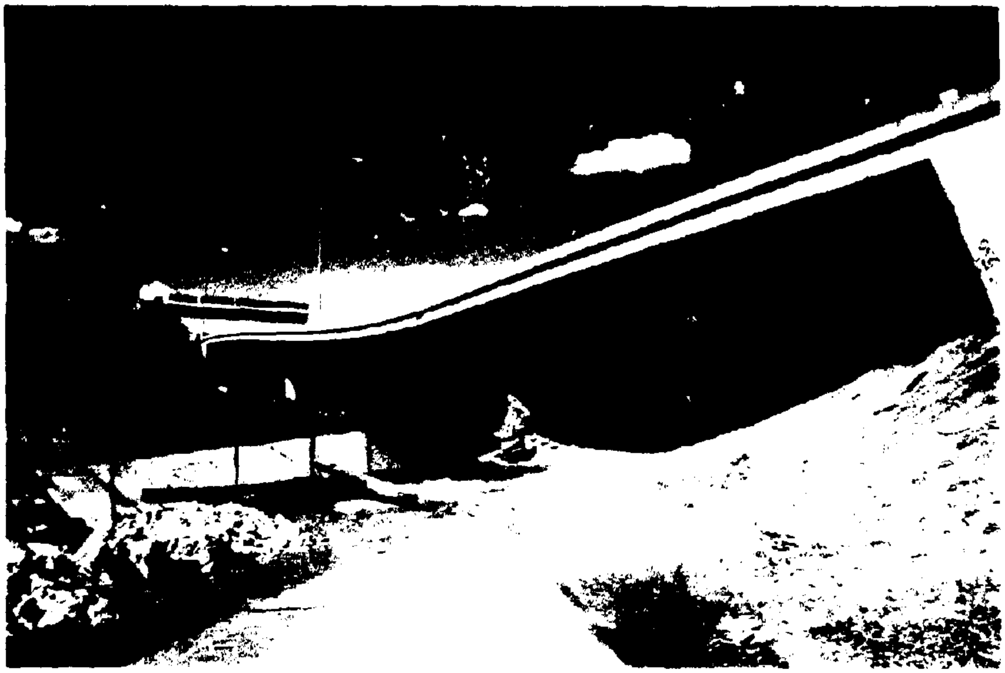


FIGURE 3-8 Bull Creek Canyon Channel Bridge - Side View

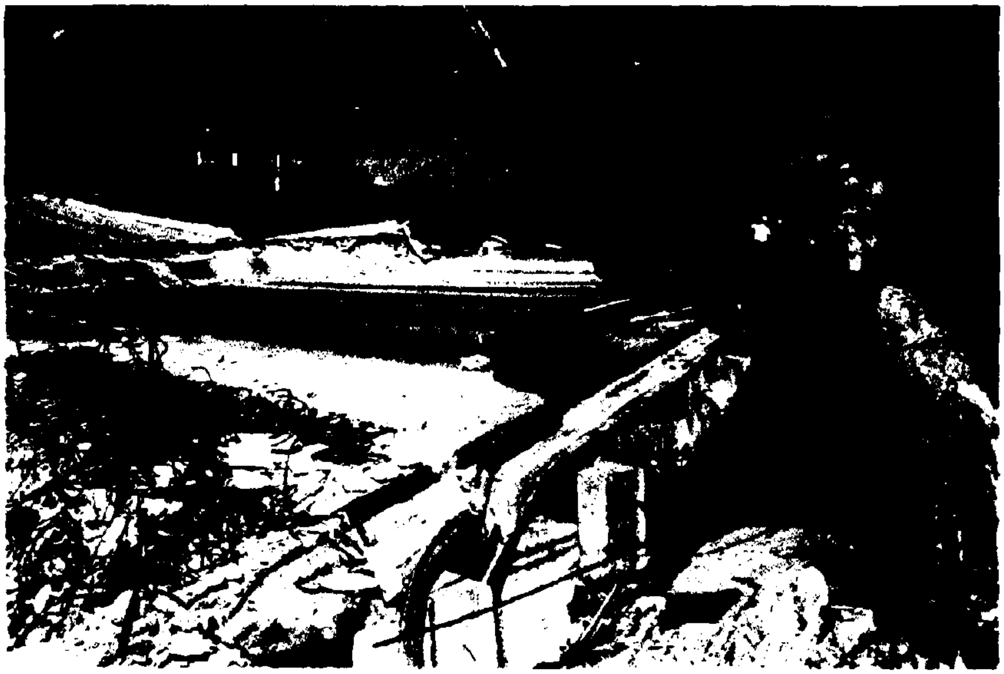


FIGURE 3-9 Mission-Gothic Undercrossing - Span 4 and East Abutment of Eastbound Bridge

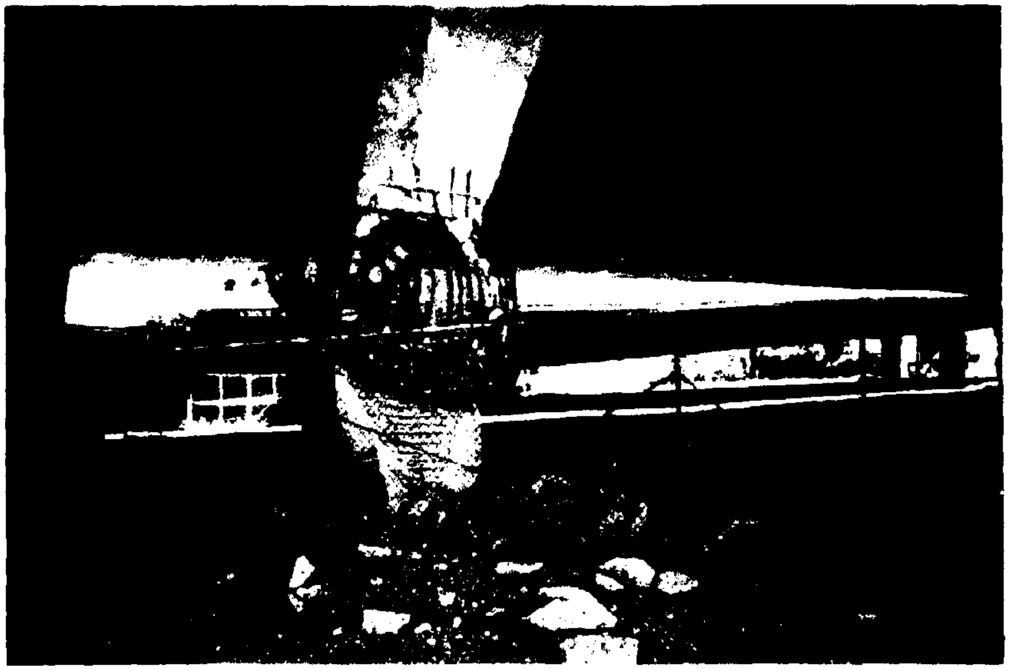


FIGURE 3-10 Mission-Gothic Undercrossing -
Hinge Formation Below Flare in Column of Eastbound Bridge (Side View)

FIGURE 3-11 Balboa Boulevard Overcrossing -
Soil Erosion at South Abutment Due to Ruptured Water Lines

FIGURE 3-12 Fairfax-Washington Undercrossing - Total Column Failure in Bent 3

FIGURE 3-13 La Cienega-Venice Undercrossing - Superstructure Settlement Due to Column Failures

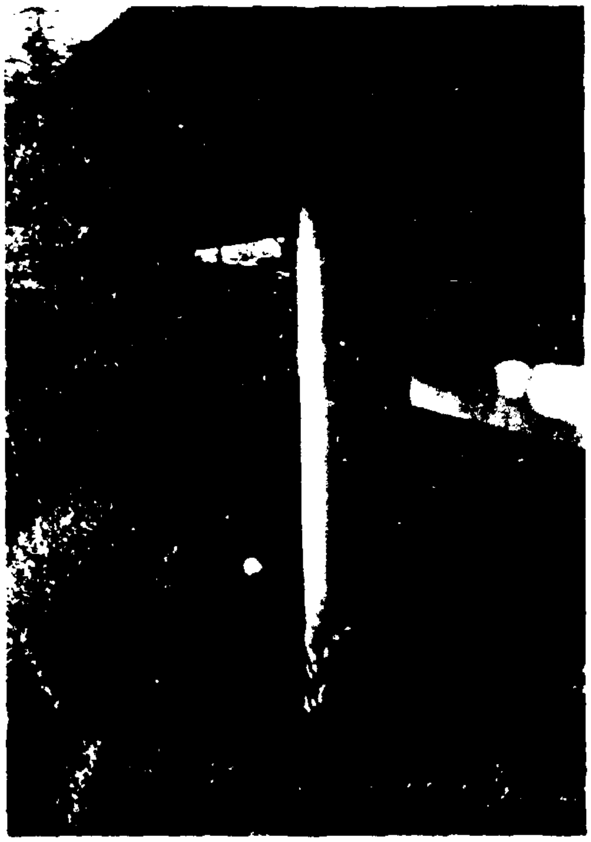


FIGURE 3-14 Ballona Creek Undercrossing on I-10 - Single Column Bent Retrofitted with Steel Jacket

Located between these two bridges on I-10 is the Ballona Creek bridge. Multicolumn bents also support this structure, but it was undamaged in this particular earthquake. This is possibly due to the fact that the columns were taller than those in the two adjacent bridges and the shear forces were less (due to a longer period and lower "plastic" column shears).

Nearby, two I-10 access ramps across Ballona Creek had single column bents and both had been retrofitted with steel jackets. No evidence of distress could be seen in either structure (Figure 3-14).

3.2 Buildings

The Northridge earthquake occurred in a densely constructed area. Large accelerations propagating over a radius of 20 to 25 miles from the epicenter (35 to 40km), had peak accelerations in excess of 0.4g horizontal and 0.2g vertical. (These accelerations are considered benchmarks by the current seismic codes.)

The area contains a wide variety of structural types which, depending upon local soil amplifications and proximity to the epicenter, were effected by the earthquake. The network set up by the California Strong Motion Instrumentation Program (CSMIP) of the California Department of Conservation/Division of Mines and Geology measured the response of several buildings, as shown in Figure 3-15. Detailed descriptions obtained by the CSMIP network are found in Tables 3-I and 3-II. The amplitude of strong ground motion in the vicinity of the foundation of each building was reduced, probably due to soil-structure interaction. The motion was amplified by structures at all sites, however, for buildings with a fundamental period in the range of 0.3 to 0.4 seconds. The predominant period reported by CSMIP in their initial reports was in the same range [1].

The focus in this section is on "structural behavior" with an emphasis on structural damage, rather than on damage in terms of dollar losses. Some of the most costly damage occurred to building contents and nonstructural components (see Section 5). Structural performance is discussed for the following types of buildings:

- Residential/ commercial, including homes, hotels and motels
- Commercial/public such as offices, warehouses, hospitals and emergency facilities
- Parking structures
- Base isolated structures

These structures comprise a variety of construction types, including reinforced concrete space frames; reinforced concrete shear wall construction; dual systems; steel space frames; unreinforced and reinforced masonry; precast and hybrid construction; and tilt-up construction. Special attention is accorded parking structures which experienced greater damage than did other

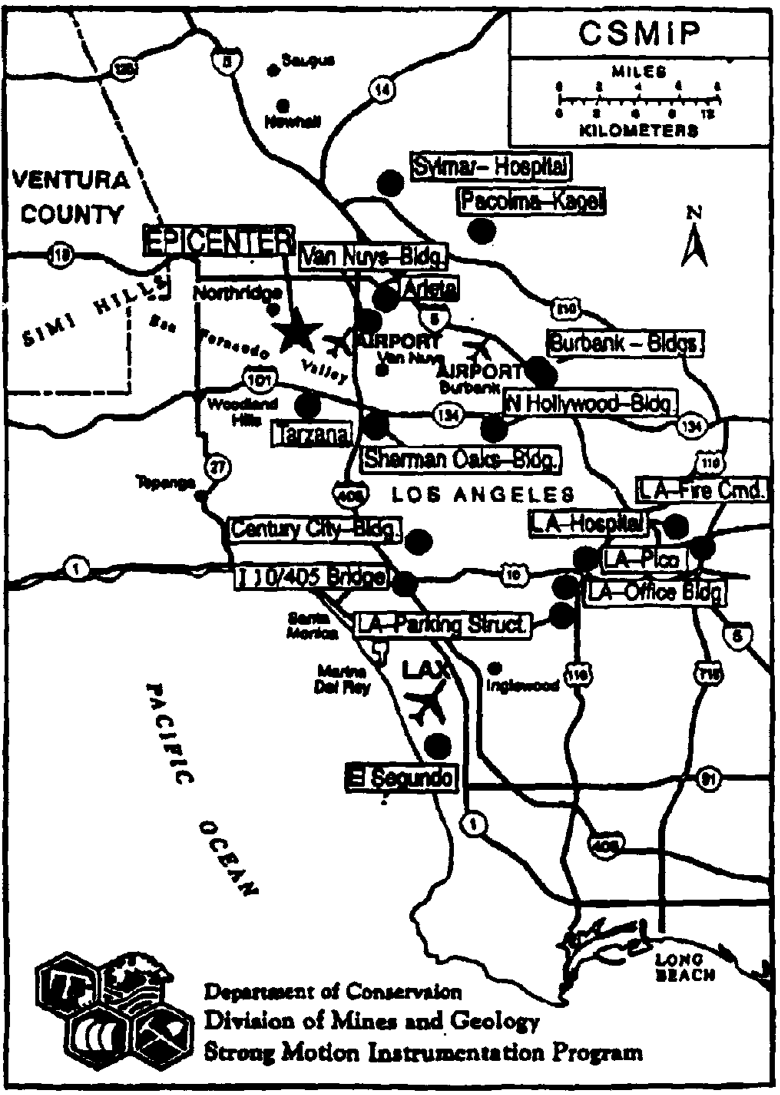


FIGURE 3-15 Distribution of Sites Recorded by CSMIP Network

TABLE 3-1 Buildings Instrumented by CSMIP Network

BUILDINGS RECORDED IN CSMIP NETWORK JAN.17,1994					
CSMIP \#	DIST (Km)	TYPE \#	LOCATION	TYPE	SOIL CONDITIONS
BUILDINGS / STORIES					
24386	6.0	B7	Van Nuys	7-stories Hotel	Alluvium
24322	10.0	B13	Sherman Oaks	13-stories Commercial	Alluvium
24514	15.0	B6	Sylmar	6-stories Hospital	Alluvium
24464	19.0	B20	North Hollywood	20-stories Hotel	Sandstone /shale
24231	19.0	B7	Los Angeles	7-stories Office (USC)	Terace deposits
24385	21.0	B10	Burbank	10-Stories Residential	Alluvium
24643	21.0	B19	Los Angeles	19-stories Office	
24370	22.0	B6	Burbank	6-stories Commercial	Alluvium
24236	23.0	B1	Los Angeles	1-story Storage	Alluvium (~130m)
24569	32.0	B15	Los Angeles	15-stories Office (Government)	Silstone
24602	32.0	B52	Los Angeles	52-stories Office	Alluvium (7[illegible] over sedimentary rock
24629	32.0	B54	Los Angeles	54-stories Office	Alluvium over sedimentary rock
24655	32.0	B6	Los Angeles	6-stories Parking	Alluvium
24652	32.0	B6	Los Angeles	6-stories Office	
24579	32.0	B9	Los Angeles	9-stories Office	Alluvium
14654	36.0	B14	El Segundo	14-stories Office	
24541	37.0	B6	Pasadena	6-stories Office	Deep alluvium fan
24468	38.0	B8	Los Angeles	8-stories Office (CSULA)	Silstone
14606	54.0	B8	Whittier	8-stories Hotel	Alluvium over sedimentary rock
14533	59.0	B15	Long Beach	15-stories Office	Terrace deposits
23622	115.0	B1	San Bernardino	1-story Commercial	Deep alluvium
BASE ISOLATED BUILDINGS					
24605	36.0	B7(BI)	Los Angeles	7-stories University Hospital	Silstone
24580	39.0	B2(BI)	Los Angeles	2-stories Fire Command Control	Silstone
14578	66.0	B8(BI)	Seal Beach	8-stories Office	Alluvium

TABLE 3-II Peak Accelerations and Amplifications in Buildings Instrumented by CSMIP Network

CSMIP	DIST	TYPE	GROUND		BASE		TOP		AMPL.		PERIOD
			H	V	H	V	H	V	H	V	(est.)
#	(Km)		(g)	(g)	(g)	(g)	(g)	(g)	(g)	(g)	(SEC)
BUILDINGS/STORIES											
24386	6.0	B7			0.47	0.30	0.59		1.26		0.50
24322	10.0	B13			0.46	0.18	0.90		1.96		0.70
24514	15.0	B6	0.91	0.60	0.82	0.34	2.31		2.82		0.35
24464	19.0	B20			0.33	0.15	0.66		2.00		1.50
24231	19.0	B7			0.29	0.25	0.77		2.66		0.60
24385	21.0	B10			0.30	0.13	0.79		2.63		0.80
24643	21.0	B19			0.32	0.13	0.65		2.03		1.50
24370	22.0	B6			0.35	0.15	0.49		1.40		0.40
24236	23.0	B1	0.41	0.19	0.29	0.11	1.61		5.55		0.20
24569	32.0	B15			0.21	0.07	0.29		1.38		1.25
24602	32.0	B52			0.15	0.11	0.41		2.73		4.00
24629	32.0	B54			0.14	0.08	0.19		1.36		4.20
24655	32.0	B6			0.29	0.22	1.21	0.52	4.17	2.36	0.55
24652	32.0	B6			0.24	0.08	0.59	0.18	2.46	2.25	0.50
24579	32.0	B9			0.18	0.12	0.34		1.89		0.80
14654	36.0	B14			0.13	0.04	0.25	0.17	1.92	4.25	1.20
24541	37.0	B6			0.17	0.09	0.21		1.24		0.50
24468	38.0	B8			0.17	0.06	0.25	0.17	1.47	2.83	0.70
14606	54.0	B8			0.19	0.10	0.49		2.58		0.70
14533	59.0	B15	0.06	0.03	0.04	0.03	0.06	0.05	1.50	1.67	1.30
23622	115.0	B1			0.05	0.02	0.15		3.00		0.10
BASE ISOLATED BUILDINGS											
24605	36.0	B7(BI)	0.49	0.12	0.37	0.09	0.21	0.13	0.57	1.44	2.30
24580	39.0	B2(BI)	0.32	0.13	0.22	0.11	0.35	0.30	1.59	2.73	2.20
14578	66.0	B8(BI)	0.09	0.04	0.08	0.03	0.15	0.16	1.88	5.33	0.70

buildings. Base isolated structures, for the first time, experienced severe excitations and their performance is discussed in a separate section.

Structural damage was classified according to the potential use of the building after the earthquake using the following scale: undamaged; serviceable needing minor or cosmetic repairs; repairable, needing major structural repairs; irrepairable, subjected to subsequent demolition; and collapsed. Only a few structures were categorized as collapsed, several more were classified as irrepairable.

Two- to three-story wood frame, three- to five-story concrete frame and five- to eight- story hybrid structures were observed to suffer the most severe damage. This is consistent with the predominant period of 0.3g to 0.4g reported in CSMIP records.

In general, damage was most severe in poorly engineered wood structures; older reinforced concrete moment resisting frames with deficient (non-ductile) details; newer reinforced concrete moment resisting frames with adequate details but lacking suitable seismic resisting systems; precast structures without suitable seismic resisting systems and lacking redundancy; unreinforced masonry structures that were not retrofitted to the current required levels; and, retrofitted masonry structures that were upgraded to a level below the maximum credible level, which also may have been exceeded in the last earthquake.

Residential Buildings

Most of the damage to residential buildings occurred in wood frame and reinforced concrete moment resisting frame structures. Most residential buildings in the area of impact are one-story wood frame construction with some brick facades. These houses suffered minimal damage (to serviceable level) which explains the relatively small number of casualties. In addition, some masonry chimneys broke off due to lack of reinforcement. A large number of houses moved off their foundations due to improper shear and tension anchors.

A large number of two- to four-story wood frame apartment buildings collapsed due to lack of suitable lateral resisting systems (see Figures 3-16 to 3-19). Most of the collapsed buildings were poorly engineered (or pre-engineered) using wood frames covered by stucco walls (or sheet rock panels) without diagonal braces or plywood shear walls (see Figure 3-20). Most buildings were based on shallow foundations and had carports at the ground floor leaving open spaces without walls or other bracing systems. Such structures developed flexible (and weak) first stories with subsequent first story column side sway collapse mechanisms. The single largest number of casualties occurred in the collapse of such a structure on Reseda Boulevard in Northridge (see Figure 3-21).

Given that many of the buildings shown in Figures 3-16 to 3-21 were near the epicenter and experienced extremely large accelerations, it is surprising that more catastrophic damage did

FIGURE 3-16 Apartment Buildings on Sherman Boulevard in Van Nuys

FIGURE 3-17 Wood Frame Apartment House with Collapsed Carport on Reseda Boulevard in Northridge

FIGURE 3-18 Wood Frame Apartment with Collapsed Carport on Reseda Boulevard in Northridge

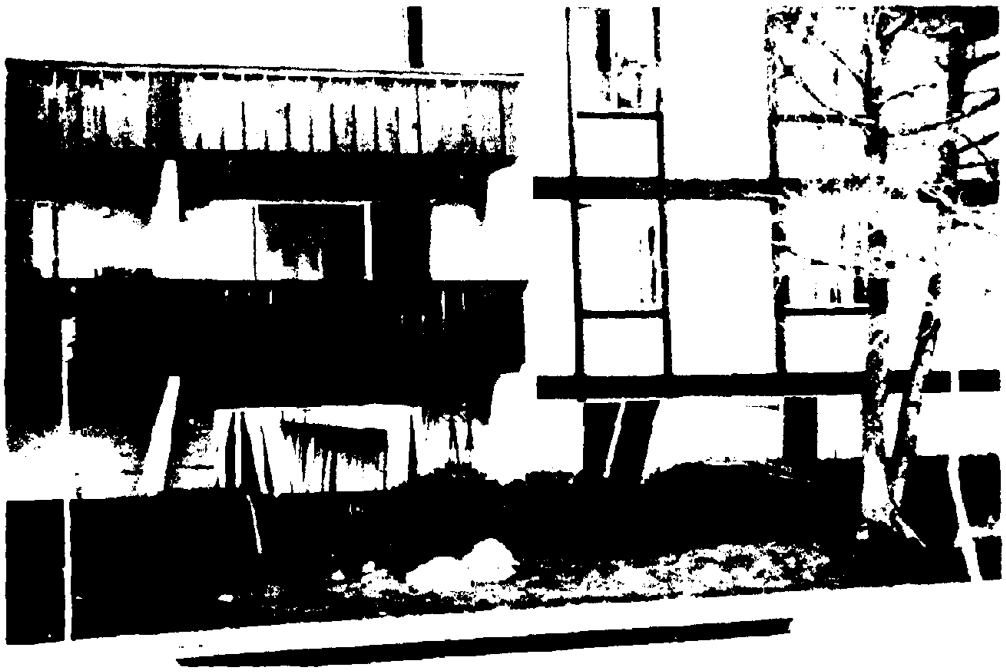


FIGURE 3-19 Lateral Deformations in the Ground Floor of Wood Frame Structure on Reseda Boulevard in Northridge

FIGURE 3-20 Typical Construction of Walls in Wood Frame Structures

FIGURE 3-21 Apartment House Collapsed (Left) on Reseda Boulevard in Northridge

not occur. In fact, several newer wood-frame structures with plywood shear walls survived the earthquake with minor repairable damage (see Figure 3-22). The Northridge area is characterized by wood frame structures lacking shear walls, thus a thorough evaluation of all buildings and eventual retrofit should be performed to improve their performance in future earthquakes.

Multi-story structures such as apartment houses, condominiums, and hotels are often constructed using moment resisting frames or hybrid systems including shear walls. Some of these buildings were structurally damaged.

A 15-story apartment building (Champagne Towers in Santa Monica) with a moment-resisting frame system in one direction and shear walls in the other was severely damaged and had to be evacuated. Significant damage was noticed in both directions. The columns developed plastic hinges and shear cracking, while the stronger beams spanning large distances did not show evidence of distress. The coupling beams between the shear walls were severely sheared, however, the walls were not damaged. The frame failure of weak columns-strong beams mechanism is characteristic of designs dominated by gravity loads for which the joint equilibrium balance was not satisfied. The failure of the coupling beams is probably a result of the design concept for motion that exceeds the design levels.

A seven-story hotel off Roscoe Boulevard in Van Nuys, a moment-resisting frame structure, was the closest instrumented building to the epicenter (approx. 7 km). Records obtained by CSMIP (see Figures 3-15 and Table 3-I) indicate that the building was subjected to ground motion in excess of 0.40g in the horizontal direction and 0.30g in the vertical direction with a response of 0.59g at the roof level (see Figure 3-23). The strong motion in all directions lasted for more than 15 seconds, with the vertical preceding the horizontal by approximately five seconds. The third floor columns at the south side developed shear splitting and concrete delamination with substantial permanent lateral deformations (see Figures 3-24 and 3-25). Since the motion was lateral only (no torsional response was recorded) it is clear that the single sided column damage is the result of biaxial flexural-shear interaction with strong vertical influences (probably some tension). The damage was somewhat visibly accentuated by the aftershocks that occurred in the first three days. The hotel had suffered nonstructural damage during the 1971 San Fernando earthquake (peak acceleration in excess of 0.24g) and was repaired. The current damage could be categorized as severe, but repairable.

Among more lightly damaged hotels, a 13-story moment-resisting space frame structure suffered severe shear split cracking in its corner columns at lower stories (see Figure 3-26). The failure was most severe at the beam-column joint connection of the main tower with the structural system of a larger front annex (see Figure 3-27). A more thorough investigation might be necessary to assess the status of such structures.

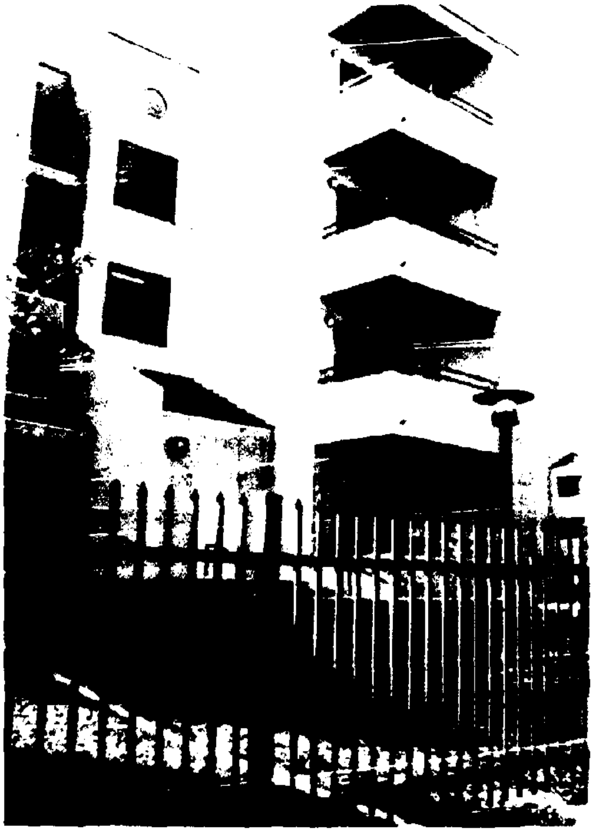


FIGURE 3-22 Newer Wood Frame Buildings at California State University, Northridge

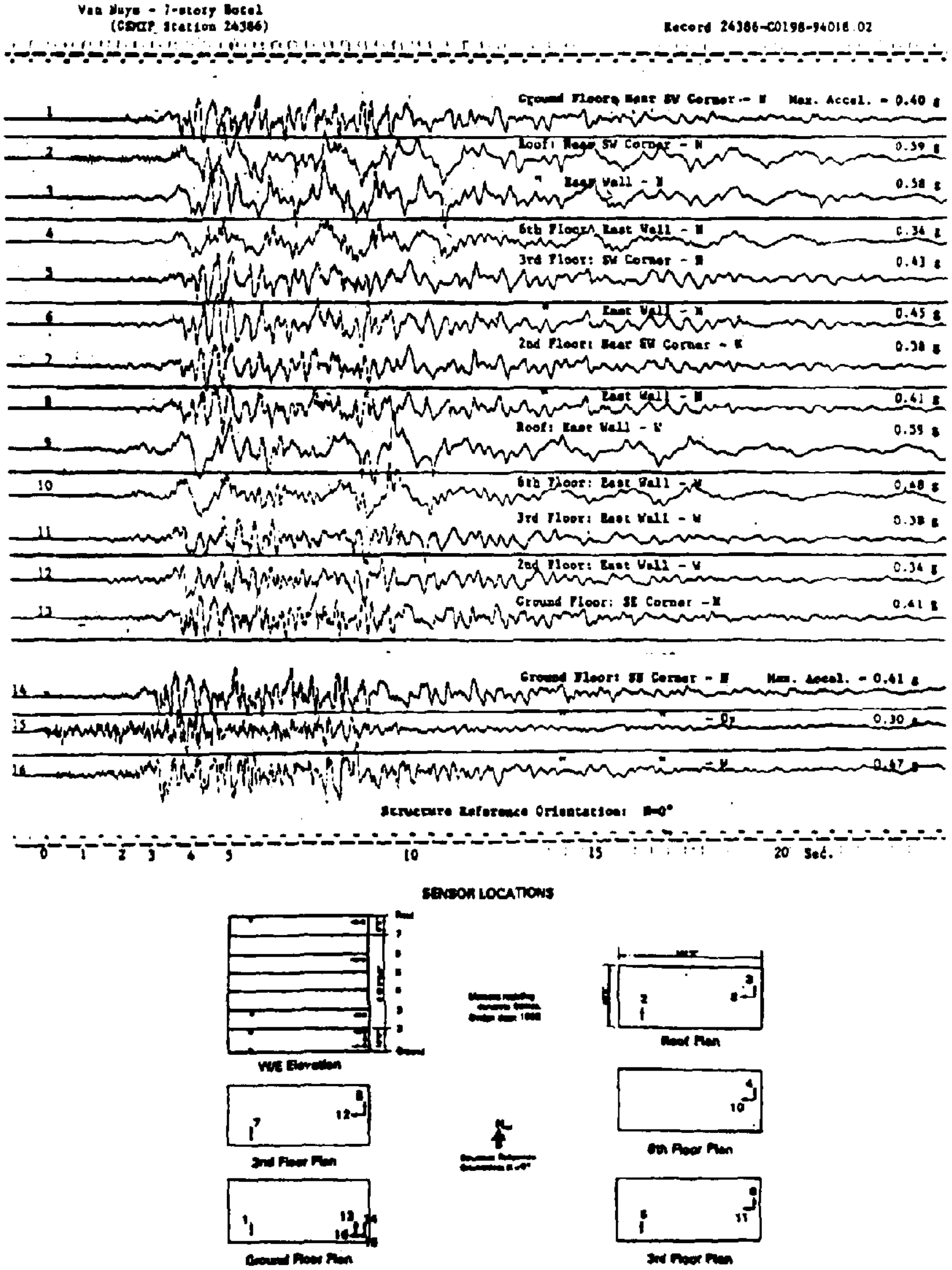


FIGURE 3-23 Preliminary Records of Motion in Seven-Story Hotel in Van Nuys (CSMIP Network)

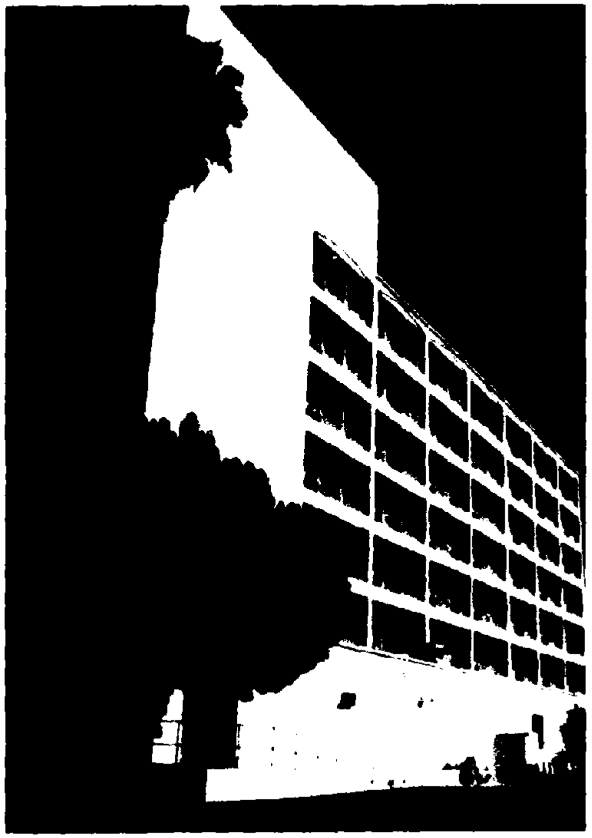


FIGURE 3-24 Damaged Seven-Story Hotel in Van Nuys

FIGURE 3-25 Damaged Columns in Seven-Story Hotel in Van Nuys

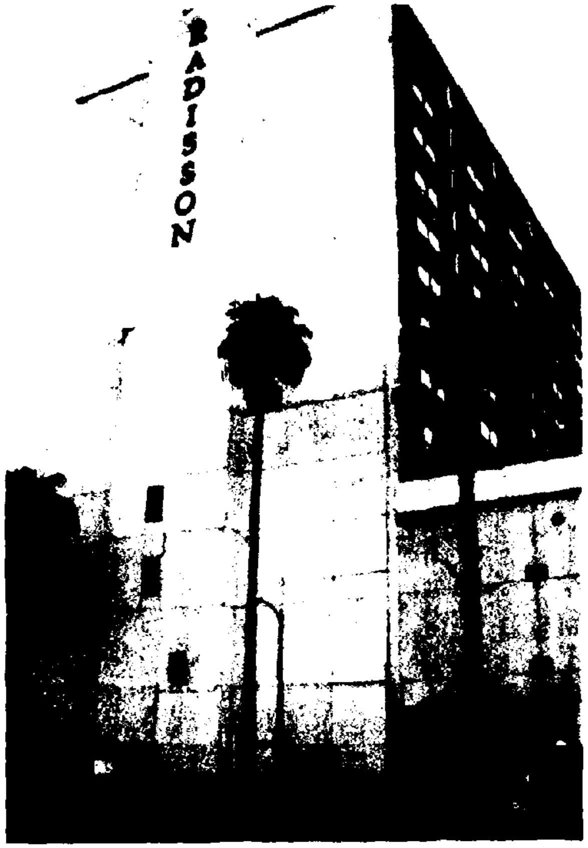


FIGURE 3-26 Thirteen-Story Hotel with Moment Resisting Frame in Sherman Oaks

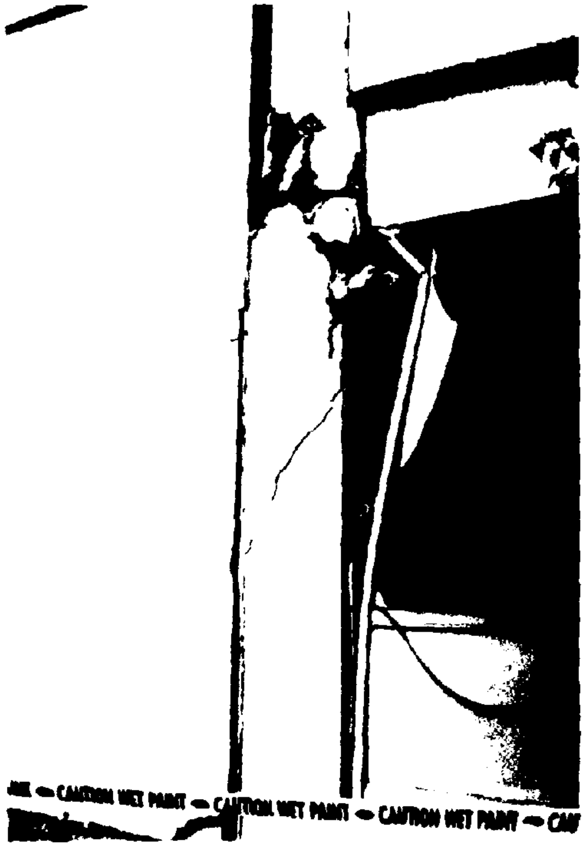


FIGURE 3-27 Column Shear Failure at First Floor of Hotel Building in Sherman Oaks

Although the structures surveyed (built in the 1960's) were built to earlier code levels, they resisted strong motion in excess of modern code requirements with only the expected permanent deformations and local failures.

Commercial, Office and Public Buildings

Commercial buildings, including shopping centers, office buildings and hospitals, are typically multistoried engineered structures with seismic details. The majority of such buildings responded with minor or no structural damage in the areas affected by the earthquake. However, a substantial number suffered structural failures or collapsed. In many cases, the buildings were unusable because of the failure of nonstructural systems (such as sprinklers, contents, etc.) which are discussed in Section 5.

A large number of reinforced concrete structures in the vicinity of the epicenter suffered severe damage. Several space frame structures within 25km of the epicenter, including structures in Northridge (less than 7km from epicenter), in Sherman Oaks (approximately 10km from epicenter), and in Culver City (approximately 25km from epicenter) collapsed. One building in Santa Monica (approximately 25km from epicenter) suffered damage beyond repair and was immediately demolished. All types of structural systems, include ductile and nonductile reinforced concrete moment-resisting space frames, shear walls, dual systems, cast-in-place or precast systems sustained structural damage.

Most damage occurred in insufficiently ductile members. The most prominent and extreme example is the partial collapse of the five-story administrative office of Kaiser Permanente on Balboa Boulevard in Northridge (see Figure 3-28). Flexural and shear failure of columns produced lateral sways and permanent deformations in the second floor of the moment resisting frame, with subsequent collapse (see Figure 3-29). Shear compression failure of beam-column joints produced substantial reduction of capacity of the entire system (see Figure 3-30). Bond slip failure in the beam ends and joint failure of poorly detailed components in the moment resisting frame produced complete loss of gravity load capacity (Figure 3-31). The lack of confining reinforcement is evident from the failures of all columns and beam-column joints. This structure has details typically used in low to moderate seismicity areas. Its failure should trigger a reassessmentof the ultimate capacities of similar buildings in areas of less severe seismicity.

Short column shear failures occurred in nonsymmetric space frames. The Barrington Medical Building on Olympic Boulevard in Santa Monica, a six-story non-symmetric moment resisting frame structure (see Figure 3-32) developed severe shear cracking in all peripheral columns (see Figure 3-33). The failure is characteristic of a torsional cyclic vibration. The building was demolished for safety reasons. Buildings in the immediate vicinity of this office also showed evidence of structural damage. The ground motion recorded for Santa Monica in the vicinity of city hall reached 0.87g in the horizontal direction with a peak velocity of approximately

FIGURE 3-28 Collapse of Five-Story Reinforced Concrete Office Building on Balboa Boulevard, Northridge

FIGURE 3-29 Collapse of Second Story of Office Building in Northridge

FIGURE 3-30 Beam Joint Failure in Office Building in Northridge

FIGURE 3-31 Failure of End Beam-Column Joint Connections in Office Building in Northridge

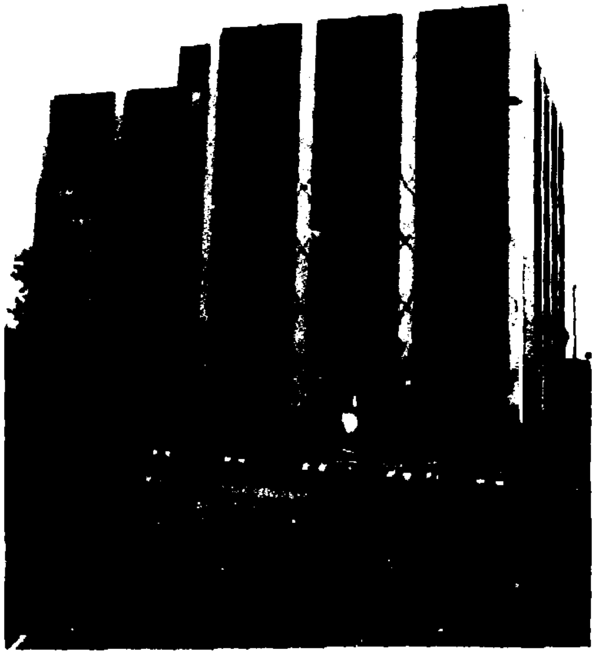


FIGURE 3-32 Nonsymmetric Moment Resisting Space Frame of Barrington Medical Building in Santa Monica

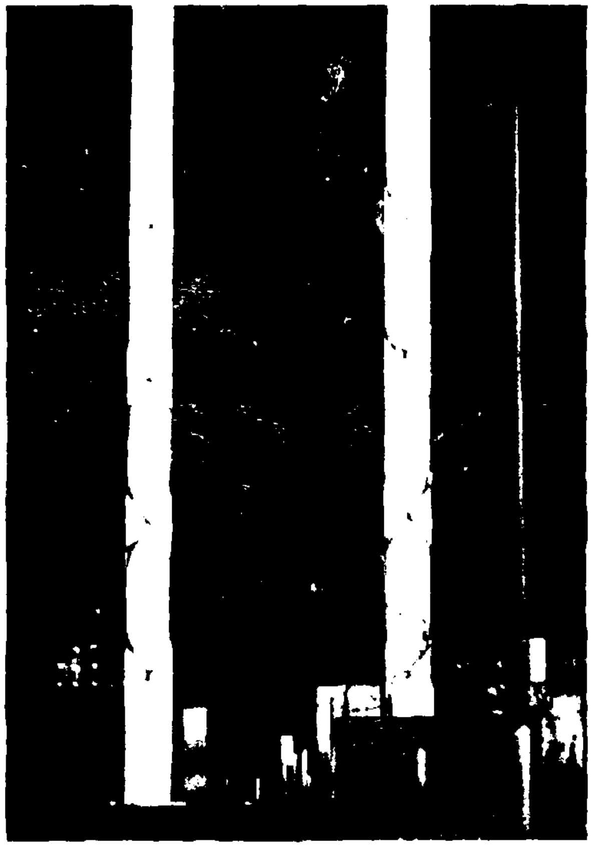


FIGURE 3-33 Typical Shear Cracking Failure from Load Reversals of Short Columns

16 in/sec (405mm/sec) and spectral values larger than 5g for structures in the same period range as the Barrington Building.

Of particular interest is a 13-story office building on Ventura Boulevard in Sherman Oaks about 10km from the epicenter (see Figure 3-34). The building is constructed with moment resisting frames in its longer direction and with shear walls in the other direction. The shear walls are oriented in the north-south direction which seems to be the main direction of shaking in the area. The walls developed shear cracks in the first four stories as well as flexural-shear cracks (see Figure 3-35). Aftershocks increased the number of visible cracks, leading to the evacuation of the building, but no evidence of spalling or delamination was noted. The structure was instrumented and recorded more than 0.4g at the base and 0.9g acceleration at its top (see Tables 3-I and 3-II). In the 1971 earthquake, the structure recorded 0.30g peak acceleration with no visible damage. After further evaluation, this structure appeared to be repairable.

A number of office buildings observed during this reconnaissance trip were built with hybrid construction. One five-story structure located approximately 10km from the epicenter (see Figure 3-36) was constructed with only one moment resisting frame along the centerline of one direction and short shear walls on the side of the eccentric stairwells, in the other direction. The structure developed torsional response with severe flexural and shear cracking in the walls with delamination of concrete and exposure of an insufficient lap splice of reinforcement at the base of each story (see Figure 3-37). Although the structure lost strength capacity, it can be repaired after further evaluation. Such structural systems are not recommended in the newer codes.

The collapse of a large department store (Bullocks) in the Northridge Fashion Center Mall (only 3km from the epicenter) was due to an apparent punching shear of the waffle slab system at all floors (see Figure 3-38). The structure was provided lateral resistance from an infilled frame with concrete panels (see Figure 3-39), which could not prevent collapse caused by combined vertical and horizontal shaking. The structural details of the waffle slab (flat plate type details) must be further investigated to determine their ability to withstand a combination of gravity loads and vertical seismic influences.

Most hospital buildings survived the event with limited structural damage (some shear wall damage at Indian Hills Hospital), except for the St. John Hospital in Santa Monica which was evacuated and closed. Several hospital administrative buildings were severely damaged in Los Angeles and near the epicenter. In most cases, the failure of concrete construction was due to lower design standards at the time of construction and slow retrofit of such buildings. However, many of the hospital buildings were put out of commission due to content damage resulting from damage to the nonstructural components and fire sprinkler water damage. The Olive View Hospital in Sylmar, rebuilt with steel plated shear walls after it collapsed in the 1971 earthquake, was seriously shaken (0.82g, 1/2 in/sec (13mm/sec)) with a response of 2.3g at the

FIGURE 3-34 Office Building with Damaged Shear Walls in Sherman Oaks

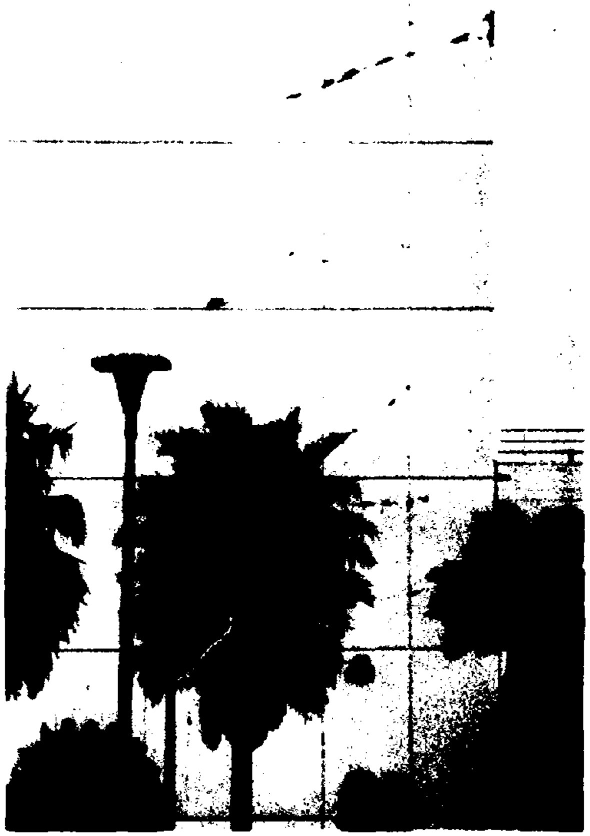


FIGURE 3-35 Damaged Shear Wall in Sherman Oaks

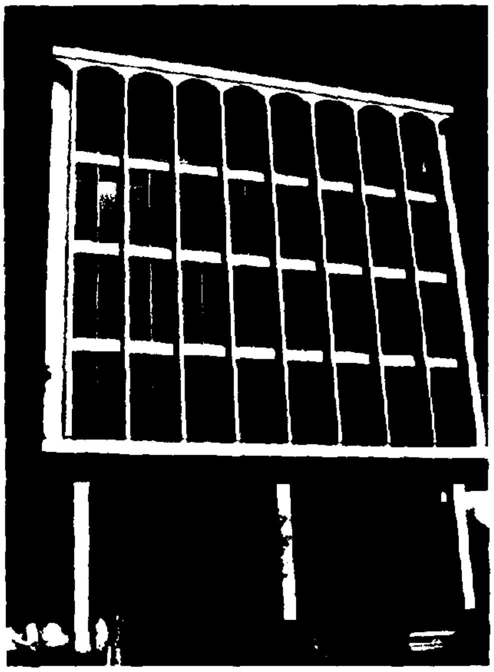


FIGURE 3-36 Five-Story Office Building Near Epicenter

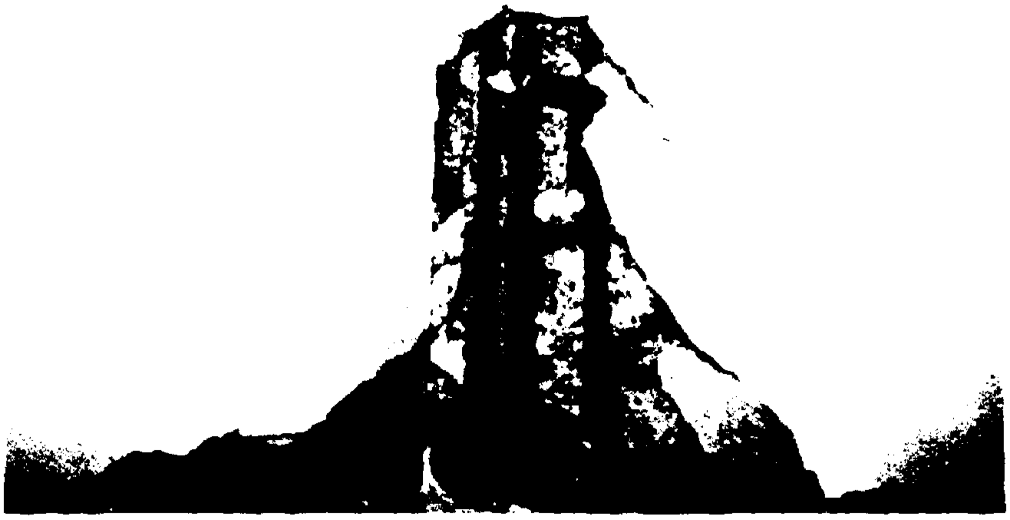


FIGURE 3-37 Shear Wall Failure at Floor Construction Joint in Office Building Near Epicenter

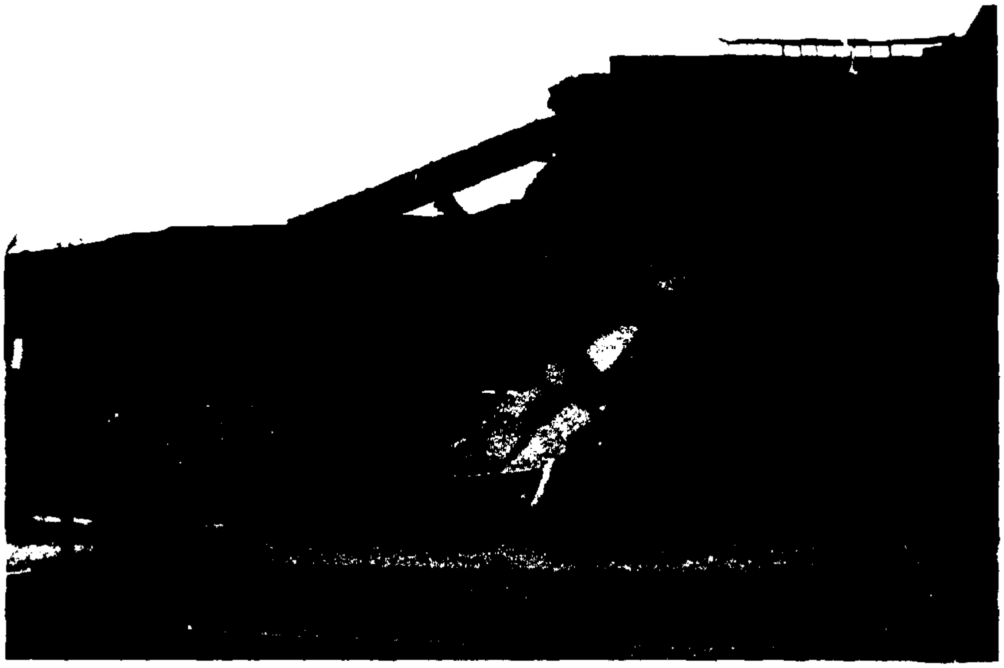


FIGURE 3-38 Collapse of Floors and Roof at Northridge Fashion Center

FIGURE 3-39 Remnants of Infills After Floor Punching at Northridge Fashion Center

mechanical room on the roof. The structure survived this extreme motion without serious damage (see Figure 3-40), however, the contents were severely damaged (see Section 5.5).

Many of the commercial and some residential buildings were constructed with load bearing unreinforced masonry (URM) walls or with nonstructural cladding masonry walls. As in most of the previous earthquakes in Southern California, these structures sustained severe damage (see Figure 3-41). In many instances, the roof supported on such walls collapsed (see Figure 3-42). Walls constructed with insufficient horizontal reinforcement and anchors sustained substantial damage (see Figure 3-43).

Of great importance to earthquake engineers is the performance of masonry structures in the Northridge area retrofitted under a program adopted by the City of Los Angeles in 1981. Some survived the earthquake with minor damage, however, a large number sustained more severe damage. The bearing walls in the building in Figure 3-44 were anchored to the floors and roof and the anchors provided sufficient restraint. However, the unreinforced corner pilaster and the side wall suffered out-of-plane permanent drift and partial collapse. The out-of-plane failure was a prevalent mode of collapse for many of the retrofitted structures. Particularly interesting are the out-of-plane failures of walls with openings. The piers between windows showed out-of-plane cracking characteristic of the "theoretical" yield lines. (No photographs of such failures are available at this time.)

Parking Structures

Among modern engineered structures, parking structures suffered the greatest damage. In fact, most collapses occurred in this building category. These collapses occurred in the immediate vicinity of the epicenter (several in Northridge) and at distances of more than 15 miles (25km) away in Culver City, Santa Monica, and Glendale. Most parking structures are constructed as simple structural skeletons with large span beams (usually larger than the columns) without walls, claddings or infills, and in many cases, made of precasted elements. They became unstable due to disconnection of the prefabricated elements, or due to column side sway mechanisms. In most cases, no redundancy was provided and the damage led directly to collapse.

Several examples are noteworthy: The two- and three-story parking garages at the Northridge Fashion Center Mall were constructed with unidirectional moment resisting frames. On one hand, the shaking produced double hinged columns in the direction of the strong frames with excessive column side sway mechanisms (with excessive deformations that rendered these garages unusable, see Figure 3-45). On the other hand, the shaking led to complete collapse of several other parking structures when it was perpendicular to the strong direction (see Figure 3-46) and no secondary system was available to absorb the effects.

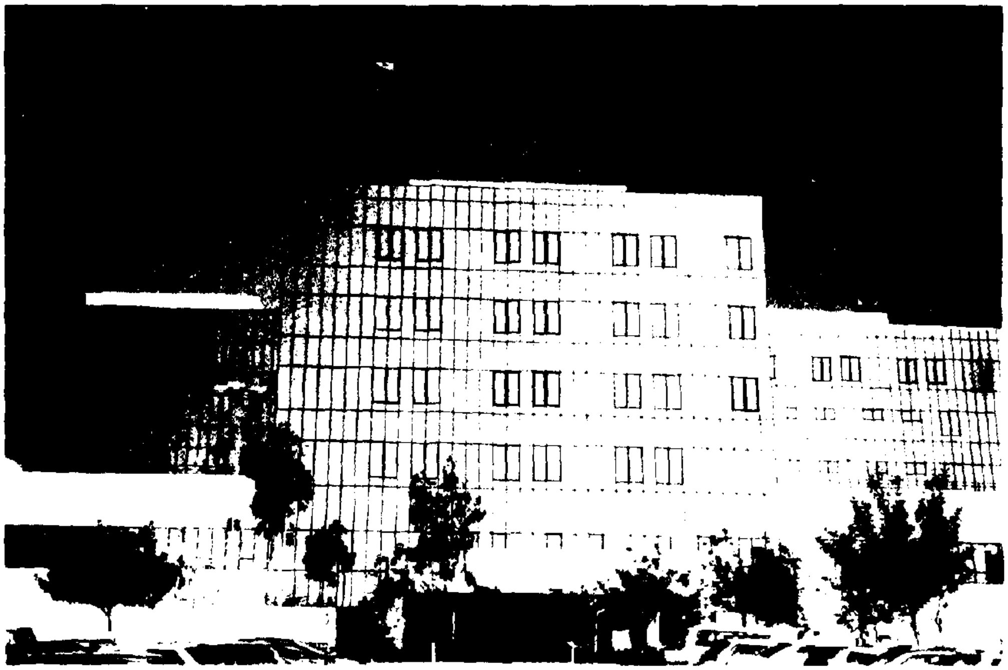


FIGURE 3-40 Olive View Hospital in Sylmar

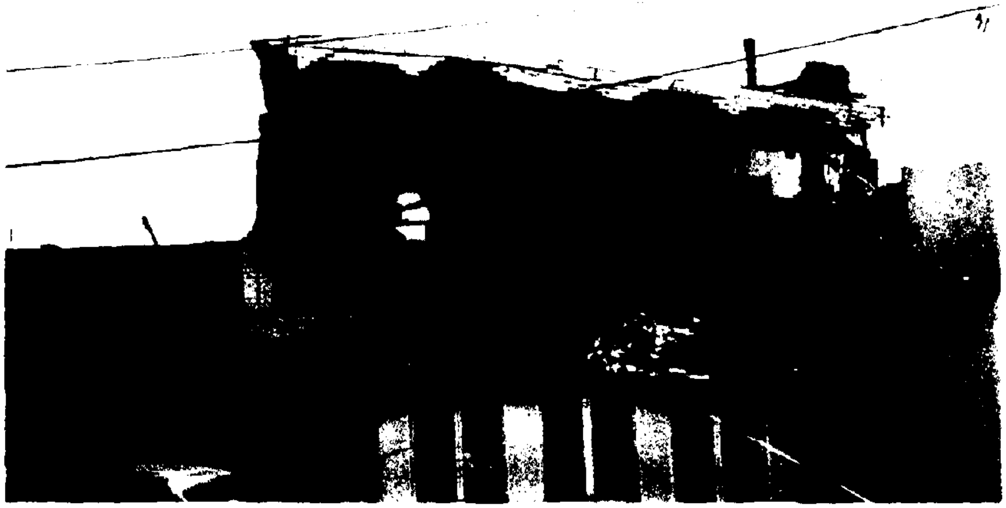


FIGURE 3-41 Collapse of Unreinforced Masonry Wall

FIGURE 3-42 Collapse of Load Bearing Unreinforced Brick Masonry Wall and Roof in Northridge

FIGURE 3-43 Failure of Reinforced Masonry Wall Without Horizontal Ties

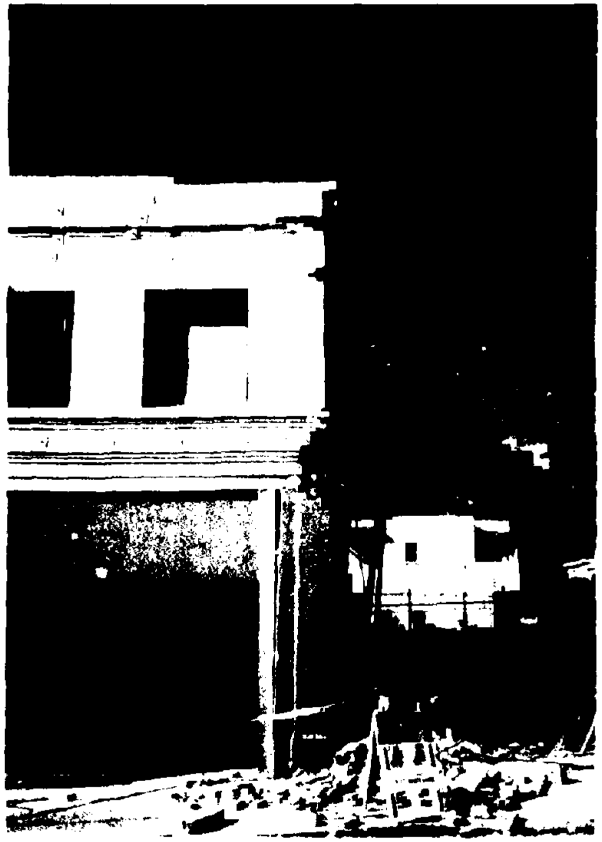


FIGURE 3-44 Damage of Retrofitted Masonry Structures

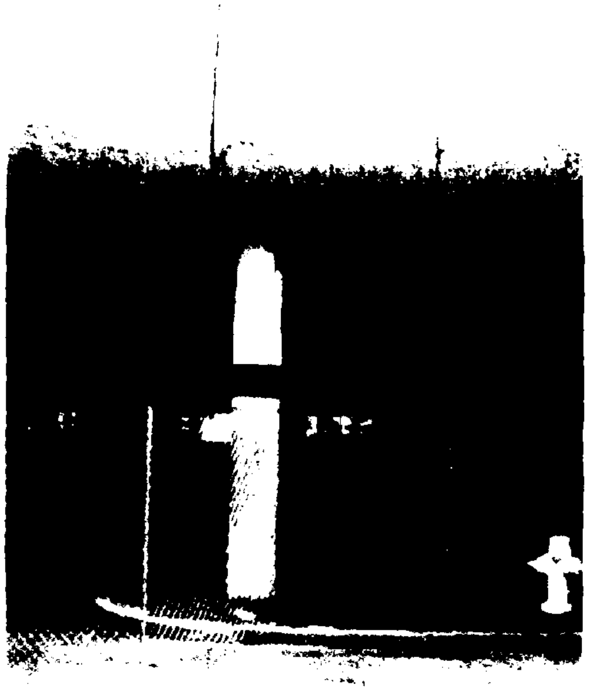


FIGURE 3-45 Column Sidesway Mechanism in Parking Garage at Northridge Fashion Center

The three-story parking garage at California State University at Northridge, a three year old precast structure with prestressed, cast-in-place slabs, collapsed due to lack of a suitable lateral resisting system (see Figure 3-47). The precast girders were unseated from the short untied corbels due to large lateral sways (see Figure 3-48) and lack of moment resistance of the slab column joint. The precast columns which bend without breakage exhibited excellent ductility, with only distributed cracking (see Figure 3-49). In general, the precast construction included a connection between a welded plate under the girder to a seat angle at the corner of the corbel. Such details proved to be difficult due to weld breakage and corbel corner failure in other garages which collapsed at the Glendale Civic Center and in downtown Los Angeles. In addition, high vertical ground shaking combined with deficient details and lack of redundancy are probably responsible for the total collapses.

Cast-in-place garages also experienced severe damage, but not complete collapses. The oversized beams, constructed for large spans, led to weak-column side sway mechanisms with short column shear failure when the openings were partially filled with half height masonry walls (Glendale Civic Center), or to shear-flexural-compression failure (see Figure 3-50). The weaker direction of most of these garages proved to be more vulnerable, developing damage such as the lateral shear shift of more than two and one half inches (63mm) of all columns above their pedestal foundations as shown in Figure 3-51 from a garage in Glendale.

The current design specifications for parking structures must be reviewed in view of the collapses and damage which occurred in this earthquake. Due to the open spans, these structures have smaller damping, therefore enhancement of damping mechanisms should be of future concern. Future earthquake resistant design provisions must also consider the vertical components of ground shaking along with the horizontal in the design of the structural system and its connection details.

Base Isolated Structures

Four seismically isolated structures were subjected to ground shaking during this earthquake. Three of the buildings are supported on laminated elastomeric bearings (the University of Southern California (USC) Teaching Hospital, the Los Angeles Fire Command and Control Facility (FCCF) and Rockwell Building 80), while the fourth is supported by helical steel springs with additional viscous dampers (GERB system).

The USC hospital, 36km from the epicenter, was subjected to ground motion in the north-south direction with a peak of 0.49g (measured in the field) that produced an acceleration of 0.37g under the isolators. This is the strongest shaking that has excited any full scale base isolated building to date. The eight-story hospital is constructed with a steel braced frame supported by 81 standard natural rubber bearings and 68 lead-rubber isolators (see Figures 3-52 and 3-53).

FIGURE 3-46 Collapse of Precast Parking Garage at Northridge Fashion Center

FIGURE 3-47 Collapse of Precast Parking Garage at California State University, Northridge

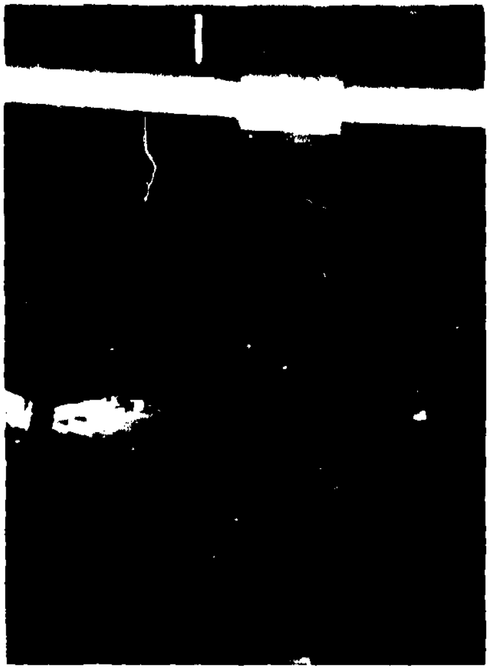


FIGURE 3-48 Unseating of Girders in the Parking Garage at California State University, Northridge

FIGURE 3-49 Curved Unbroken Columns in the Parking Garage at California State University, Northridge

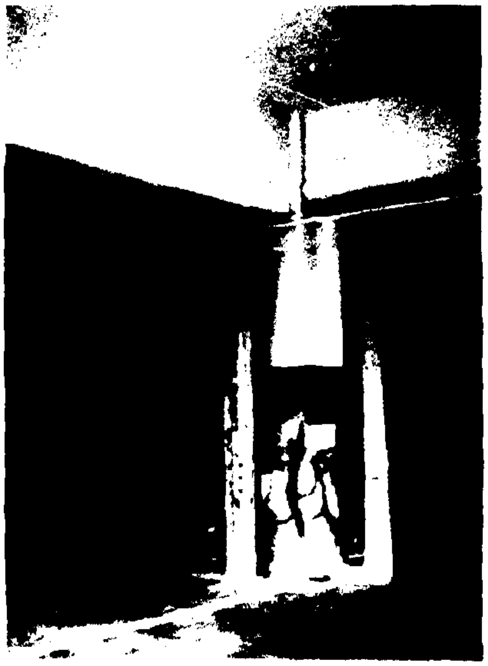


FIGURE 3-50 Shear Compression Failure in Column of Cast-in-Place Garage in Sherman Oaks

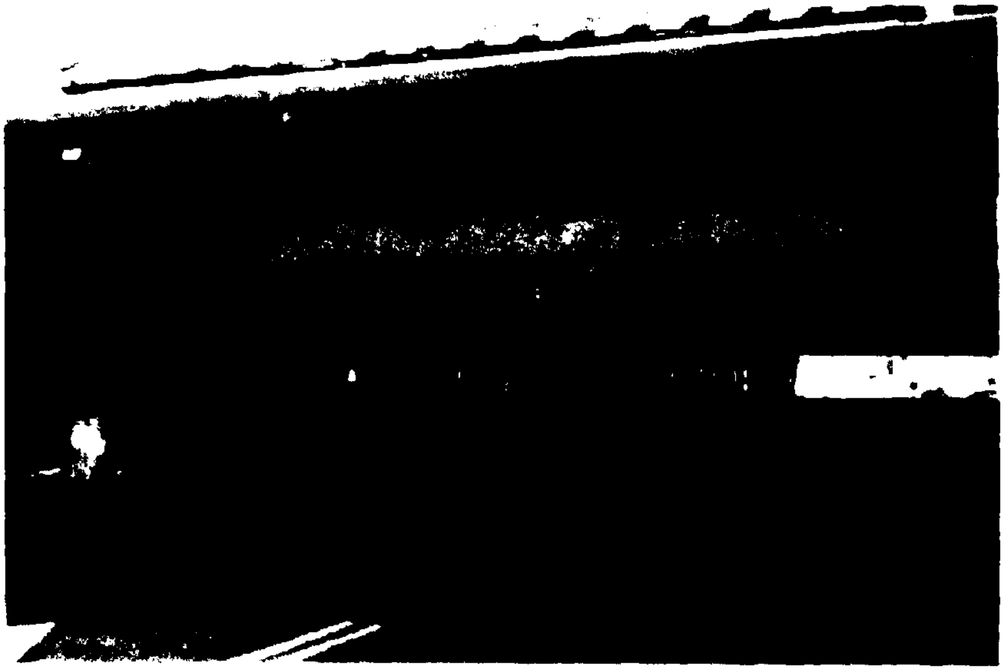


FIGURE 3-51 Shifted Columns Above Pedestal in the Short Spans Direction

FIGURE 3-52 University of Southern California Teaching Hospital

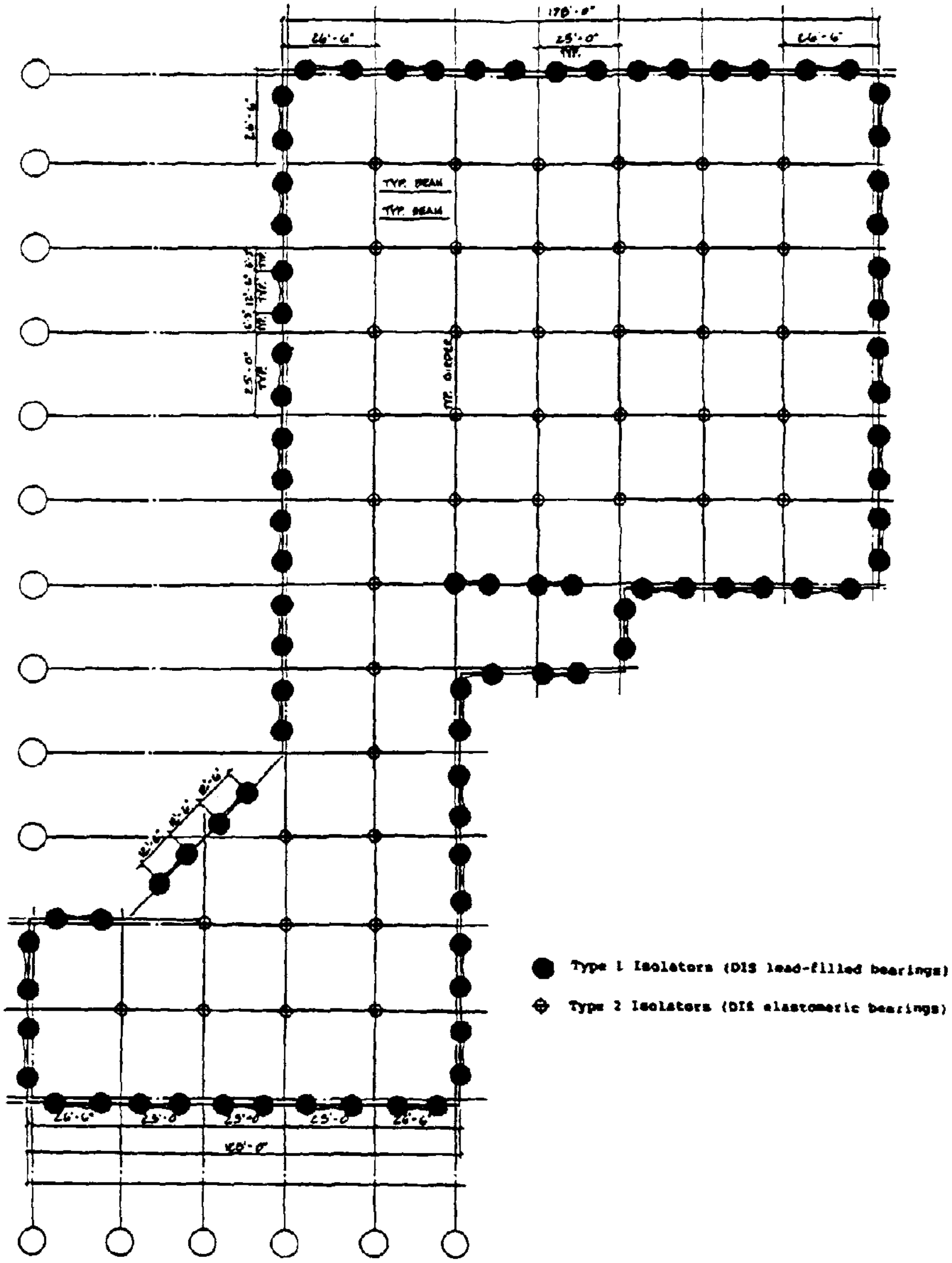


FIGURE 3-53 Plan of Isolator Layout in USC Teaching Hospital

The peak acceleration response above the isolators was reduced to 0.13g, while the roof acceleration reached only 0.21g (effectively only 57% of the base excitation).

For a fixed base structure of the same flexibility (fundamental period), the response would have been amplified (elastically) approximately three times. In the east-west direction, the structure was excited with a "minor" shaking of 0.16g at the base which was reduced to 0.07g above the isolators. This in turn produced 0.16g at the roof (center).

Although the reduction of response is not dramatic for this direction, the isolation did not produce amplification of base shaking. The structure did not show any signs of distress and remained completely functional throughout the earthquake and the aftershocks. Since this is the first strongly excited base isolated structure, the evaluation of recorded data should be valuable in accrediting this type of construction.

The FCCF structure serves as the headquarters for the Los Angeles County fire dispatch units. The two-story steel braced frame structure, located 39km from the epicenter, was subjected in the east-west direction to 0.22g base motion, which produced 0.21g above the isolators in one side of the building and 0.24g at the roof in the same side.

The response is within the expected range. However, on the other side of the building the acceleration above the isolators had several peaks of 0.35g that produced corresponding peaks of 0.32g at the top. These high-frequency spikes are probably due to the crushing of several tiles at the steel expansion joint that spans the isolation gap at the entrance to the building. The tiles were not structural elements but an architectural detail which had also failed during the Landers earthquake in 1992. At that time, they were replaced with stronger ones. Their failure probably introduced several acceleration spikes at the first floor. With proper construction, this local effect could have been avoided. In the other direction, the response was entirely as expected with a lower response above the isolators and at the roof top (i.e., 0.18g at base, 0.07g above isolators and 0.09g at top). The vertical response of the structure, however, produced some amplification of the base motion (0.11g at base vs. 0.30g at second floor). This behavior merits further investigation. Overall, the structure did not have any sign of damage and the FCCF remained functional during and after the earthquake.

A third isolated structure in Seal Beach, 65km from the epicenter, was subjected to 0.09g excitation which was amplified to 0.15g at the roof level. The eight-story structure has a reinforced concrete moment-resisting frame with waffle floor slabs. Fifty lead-filled elastomeric isolators are located at the first floor in the midheight of columns. The excitation was not large enough to engage the lower stiffness of the isolators.

Two identical three-story residential buildings in Santa Monica were constructed with steel braced frames and supported by an isolation system of GERB steel helical springs at the corners and viscous dampers produced by GERB. The site is 24km from the epicenter and was subjected to accelerations over 0.8g horizontally and 0.3g vertically. The buildings amplified the base motion both horizontally and vertically. Structural damage at the ground floor indicated that excessive motion was present in the response. The vertical motion was also substantially amplified with displacement peaks over one inch (25mm).

3.3 Industrial Facilities

Reconnaissance of industrial facilities following the earthquake focused primarily on larger facilities located near the epicenter and industrial sites near strong motion instruments that recorded relatively high ground accelerations. Initial investigations were largely concentrated along the Southern Pacific railroad from Interstate 405 through Northridge and Chatsworth, and passing within one half kilometer of the heavily damaged Northridge Fashion Center. Damage was sustained in Santa Monica as well as north of the epicenter in Valencia, Newhall and the Placerita Canyon.

Performance of industrial facilities in the affected areas ranged from relatively good with business interrupted for less than one week, to almost total losses. Anchored equipment generally withstood the event without incident. However, exceptions, such as damaged vibration isolator mounts and the failure of process equipment (see Figure 3-54) subjected to excessive piping loads, were observed.

The San Fernando Valley is generally void of heavy "smokestack" type industries. The region is home to numerous Fortune 500 defense, aerospace, entertainment, and services companies. Thousands of smaller manufacturers are located in the affected area, including companies that support the high technology defense and aerospace industries. The following paragraphs summarize the performance of several industrial facilities subjected to peak horizontal ground accelerations at 0.5g to 1.0g.

A large data processing center housed in a modern tilt-up building sustained damage to nonstructural elements. Items that were not bolted down such as files, personal computers and work stations, fell to the floor. Key data processing equipment, engineered raised computer floors and plant facilities such as back-up power equipment, performed relatively well. The uninterruptible power supplies (UPS) and associated equipment such as batteries, (see Figure 3-55) diesel generators and electrical gear performed almost without incident. The positive performance of key data processing and support equipment, an emergency operations center with a written emergency plan, and the extraordinary efforts of employees and contractors led to restoration of key services within about two hours.

One of the larger manufacturing plants in the San Fernando Valley has undergone an extensive seismic retrofit program over the past few years. Additional shear walls or braces and anchorage were installed to strengthen buildings, tanks and equipment. The facility survived

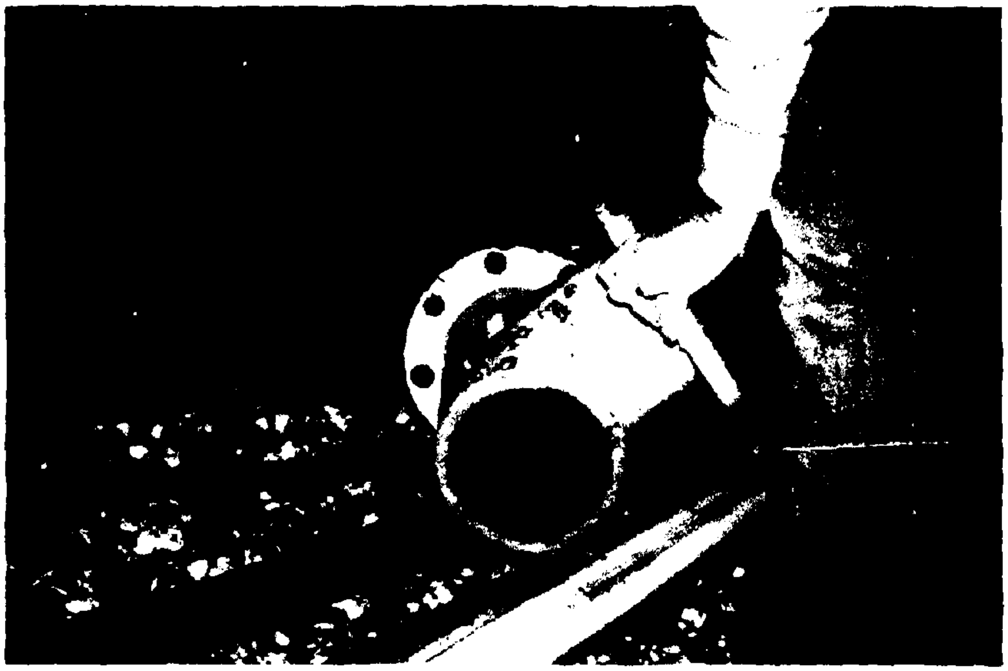


FIGURE 3-54 Process Tank Anchorage Failures Led to Excessive Piping Loads, Resulting in Failures in Flanged Piping

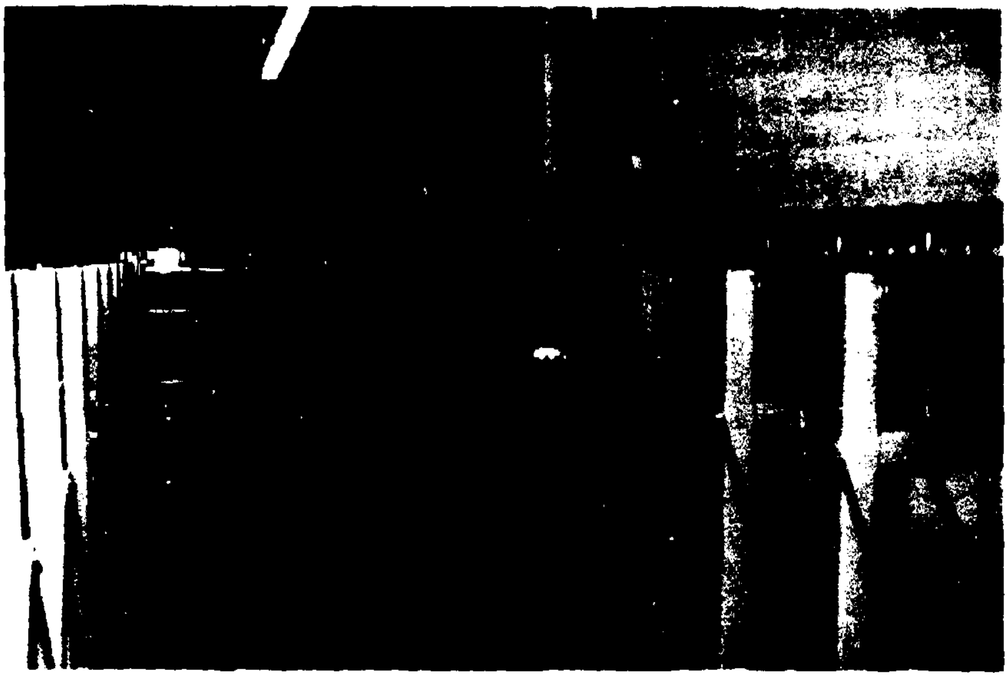


FIGURE 3-55 Engineered Equipment such as these Braced Battery Racks were not Effected by the Earthquake

the earthquake with minimal damage such as failure of fire protection piping, dislodged building insulation panels, loss of stored inventory, minor misalignment of production lines, spalling at several tank footings, and miscellaneous architectural damage. The plant resumed production within one week of the earthquake.

A beverage can facility, located in Chatsworth approximately one and one half miles (2.5km) west of the Northridge Fashion Center, is one of the largest manufacturing/industrial facilities in the San Fernando Valley. This plant, completely renovated and modernized in 1990, suffered extensive damage to both the aluminum beverage can manufacturing equipment and to the mechanical and electrical support equipment. The plant building sustained only minor structural damage but the plant equipment damage amounted to 20% of the 1990 renovation cost. Not included in the loss estimate is the production loss (the plant was in 24-hour operation prior to the earthquake) during the estimated ten week repair period before the plant returns to production. The plant air conveyor system must be completely replaced. Cooling water pipe supports were damaged and the fire sprinkler system had numerous leaks. Large ovens and other equipment pulled their anchors and shifted one to two inches (25 to 50mm). An anchored waste oil tank (approximately 10,000 gallons) pulled its anchors and shifted, breaking the discharge pipe and emptying its contents. A 250,000 gallon unanchored firewater tank experienced an "elephant's foot" buckle around the entire base circumference. The tank discharge pipe was damaged, apparently by tank uplift, and the tank lost its contents. It should be noted that another slightly smaller unanchored fire tank at an adjacent (within one third of a mile) large storage facility also sustained a circumferential elephant's foot bulge.

A smaller 160,000 square foot Chatsworth industrial facility suffered moderate damage to older equipment, including equipment anchorage failures and overturned tanks. Newer equipment that was designed for seismic loads did not suffer significant damage. The facility was ready to return to production within four days of the earthquake pending resumption of the potable water supply.

Cogeneration Facilities

Several modern cogeneration plans are located within the region affected by the Northridge earthquake. These plants support a diversity of larger facilities including hospitals, petrochemical plants, and large office buildings. The central plants generally provide electricity, heat, cooling and other services depending on the type of facility. Several of the plants are also Independent Power Producers, providing electricity to the utility electrical distribution system.

Some facilities were located within a few kilometers of the epicenter, with others at more distant locations. A six megawatt (6mw) gas turbine unit was subjected to a 0.9g ground motion and was operational within a few hours. A 25mw gas turbine unit located in the Santa Clarita Valley was also operational within a few hours. Preliminary investigations indicate that control logic malfunctions are a significant factor for the restart of units that are undamaged by the earthquake.

Some of the smaller facilities are located in areas that sustained substantial structural damage to surrounding buildings. In one case, automatic closure of a seismic gas shut-off valve isolated gas to the boiler. Backup power to restart the boiler was provided by a manual start diesel generator, enabling plant operation following resetting of the gas valve.

The largest cogeneration facility affected by the Northridge earthquake is a 110mw combined cycle plant that includes two gas turbines and a steam turbine. The facility was not in operation when the earthquake occurred due to scheduled maintenance. The most significant damage was sustained by several large storage tanks and smaller tanks associated with the water treatment system. Storage tanks that sustained the greatest damage are older bolted tanks that pulled anchor bolts and leaked at seams. Newer storage tanks sustained minor pulling of anchor bolts, however, tank displacements resulted in failures at attached lines (see Figures 3-56 and 3-57).

3.4 Dams

Dams performed well in the Northridge earthquake. Following the 1971 San Fernando earthquake, most major dams in the state have been dynamically analyzed for the maximum earthquake that could be imposed on the dam. Those dams that did not meet these seismic criteria, have been rebuilt, modified, operated at a reduced level or removed from service.

There are 120 dams within 46 miles of the epicenter of the Northridge earthquake. The California Department of Water Resources, Division of Safety of Dams (DSOD) has jurisdiction over 108 of these dams and the remaining 12 are owned by the federal government. All major dams were inspected by their owners immediately after the earthquake. Some of the major dams were further inspected by their staff or contract engineers. Of the dams under state jurisdiction, 101 were inspected by DSOD engineers within the first five days. The remainder were either dry, under construction, and outside the area. All have since been inspected. All state and federal dams performed satisfactorily and no emergency situation existed.

Twelve of the 108 dams nearest the epicenter had some minor horizontal and transverse cracking, settlement, minor horizontal movement and one small storm water dam had a minor slope failure. Pacoima dam had cracking in both abutments and damage to its access ramps and stairways. The total capacity of the flood control basin is 3,770 acre feet. Storage capacity has been temporarily limited to 1,000 acre feet while engineers are making further investigation of the abutments. The dam performed satisfactorily.

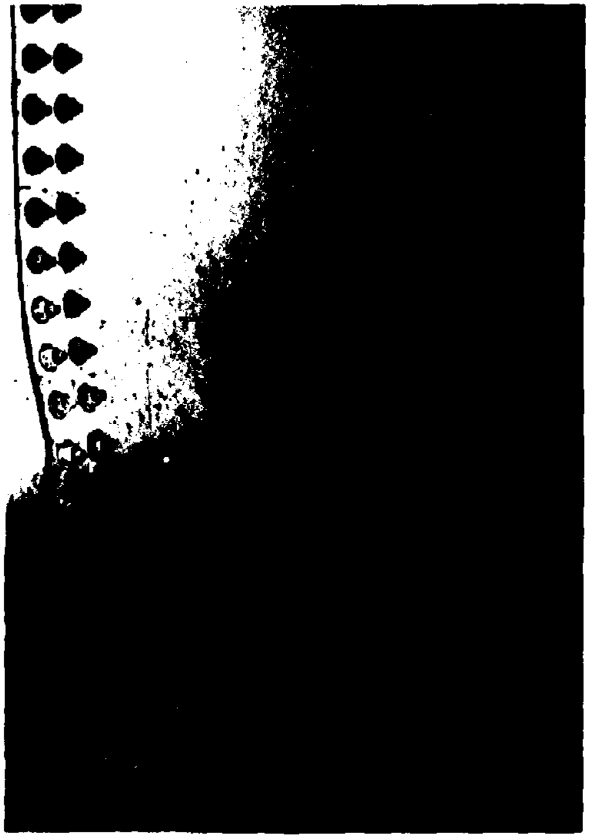


FIGURE 3-56 Older Storage Tanks Sustained Pulling of Anchor Bolts, Elephant's Foot Buckling and Leaks at Bolted Seams

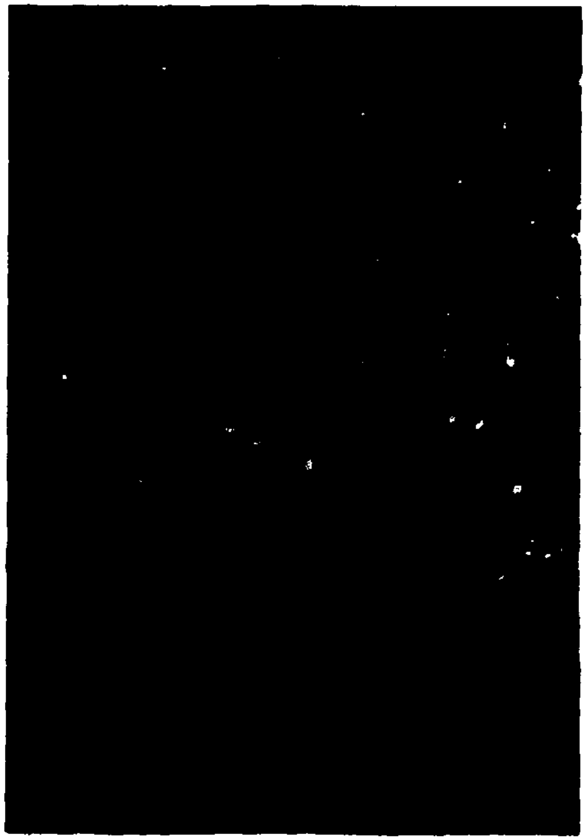


FIGURE 3-57 Most Recent Vintage Anchored Storage Tanks Were Not Damaged by the Earthquake - This Tank Was an Exception, Pulling Anchor Bolts About 1/4 Inch

SECTION 4
LIFELINES AND UTILITIES

4.1 Telecommunications

As in any natural disaster, the performance of communications systems during and after earthquakes crucially impacts emergency response and short-term and long-term recovery. Specifically, communications systems play an important role in many areas which includes locating, requesting help, and providing assistance to injured people or those who are in imminent danger; dispatching help to areas of fire following earthquakes; damage assessment and providing input to local, state, and Federal agencies; providing crucial information, such as the location of public shelters, water and food supplies, and road closures, to the general public; providing law enforcement and surveillance of the impact area providing national security; supporting financial transactions; planning and prioritization of recovery; and supporting data transfer activities.

Communication systems include the telecommunications network (i.e., Public Switched Network), cellular mobile radio systems, radio and TV stations, dedicated telemetry systems, cable television, news media (printed), electronic mail networks, and ham radios. In general and by far, the telecommunications network is the most important of all communications systems, especially immediately after major disasters such as earthquakes. This section concentrates on the performance of the telecommunications network in the Northridge earthquake.

Figure 4-1 shows the locations of local exchange carriers' major facilities in the earthquake area, which includes end offices, central offices with access tandem and remote switching units. Some of the inter-exchange carriers, (i.e., long distance carriers) have points of presence in one or more of these facilities. There are cable (copper and fiber optic) and radio links between these facilities, which are not shown in this figure. The majority of these facilities lost commercial electric power and had to rely on backup power. Interruption of city water service caused some disruption to the cooling functions of central offices.

Immediately after the earthquake, local exchange carriers (LECs), such as Pacific Bell and GTE, reported disruption and jams in the local telephone traffic throughout the earthquake-affected area, including Northridge, Canoga Park, Newhall, Simi Valley, West Los Angeles and Pacific Palisades. Inter-exchange carriers (IECs), such as AT&T and MCI, implemented network management controls to curtail long-distance calls into the state to free lines for emergency calls, but most area residents could make calls out of state.

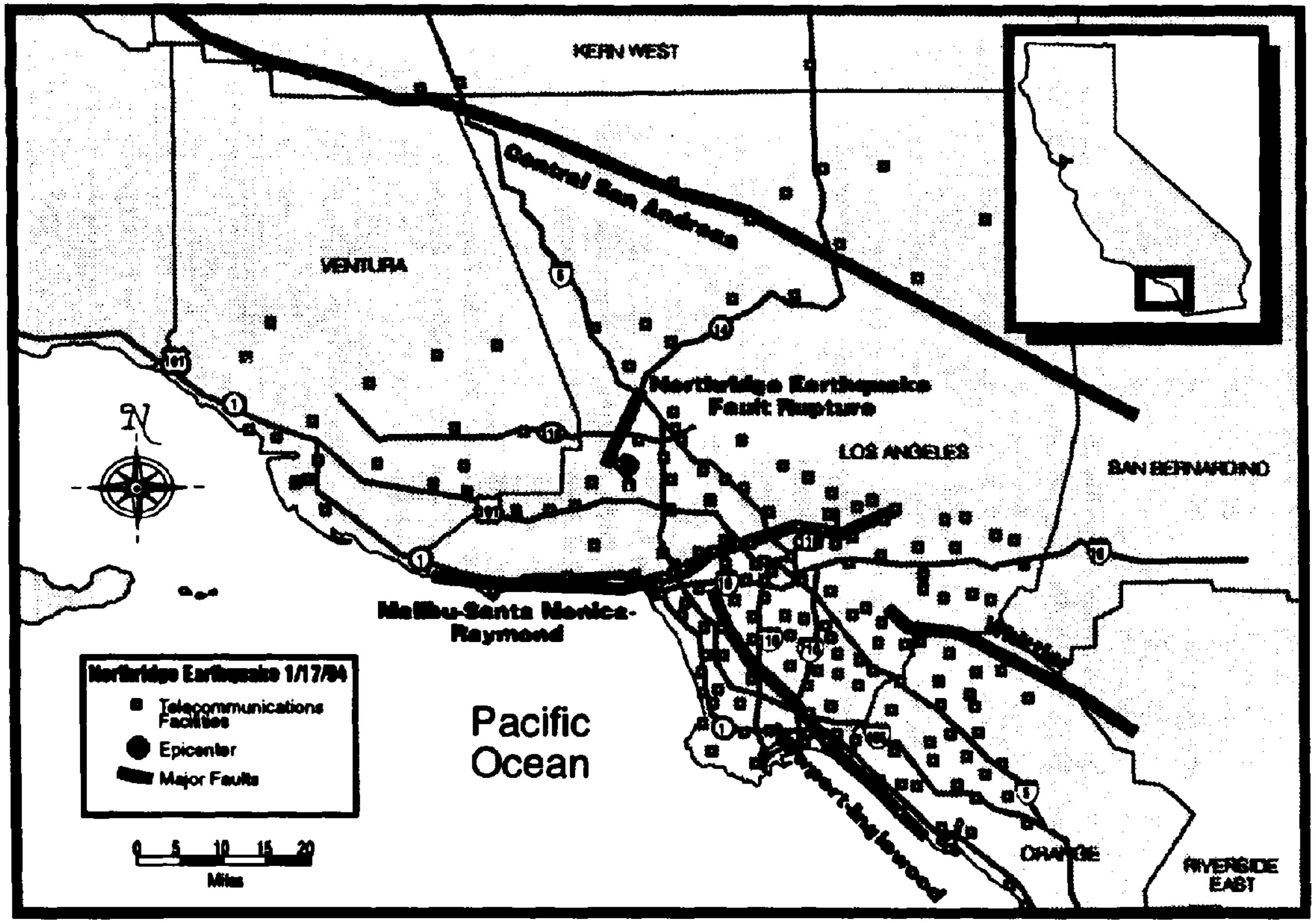


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FIGURE 4-1 Location of Local Exchange Carriers' Major Facilities

In the epicentral area, the loss of power disrupted an IEC unit, cutting off long-distance service to thousands of customers in all four of Southern California's area codes, including 213 for Los Angeles, 310 for West Los Angeles, 805 for Bakersfield and 818 for Pasadena. One of the IECs lost service on two of its main electronic switching systems in its office near the epicenter because it could not start a backup generator and had to rely on batteries, which were depleted after about six hours. Inter-exchange carriers generally relied on backup power supplies and, in some instances, needed to truck in water for cooling systems. In several central offices, circuit cards were shaken loose on the switches, which required manual reinsertion. Some limited interruption was reported in both local and long distance service caused by damaged telephone system buildings, malfunctions of equipment, and damaged phone lines.

Computer users turned to electronic mail when they were unable to make long-distance telephone calls into and out of the earthquake area. However, there is a report that some computer networks had been knocked out. Cellular telephones proved to be very useful immediately after the earthquake but also became saturated very soon. Usage increased on carriers' cellular systems following the earthquake. PacTel Cellular experienced a 25% increase in calls going through its system. The cellular network was operating at 95% capacity because of downed land lines. The immediate impact of the earthquake was even felt in the San Francisco Bay area. PacTel Cellular in Walnut Creek was forced to switch to generators and battery power after it lost commercial electricity. McCaw Cellular Communications Inc. reported that a small number of cell sites were damaged and electrical power was cut off to 20 other cells in its Los Angeles area operations. Portable generators were flown in from around the country and cells were brought back to service within few days.

4.2 Water and Wastewater Systems

Water Supply

Water supply to Southern California is provided by local groundwater basins and imported supplies from the Colorado River and Northern California. The earthquake disrupted the four pipelines from Northern California serving the Santa Clarita and San Fernando Valleys which supplies three water treatment plants. The plants have a capacity of 25, 550, and 600-mgd. The breaks in 54, 77, 85, and 120-inch diameter steel pipelines were repaired in two to ten days (see Figures 4-2 and 4-3). The treatment plants sustained minor damage, such as settlement around the plants, leaks at construction joints, leaks in plastic chlorine solution lines, and damage to wooden baffles in the basins (see Figures 4-4 through 4-7). Supply to customers was available in most areas from storage and other regional sources, but was not available from the treatment plants due to distribution system damage (See Figures 4-8 through 4-11). Boil water notices were given after the earthquake and lifted in Los Angeles on January 29th; however, remained in effect in the Santa Clarita Valley until February 4th.

FIGURE 4-2 Repair of Van Norman Pumping Station Discharge Line (54" wsp)

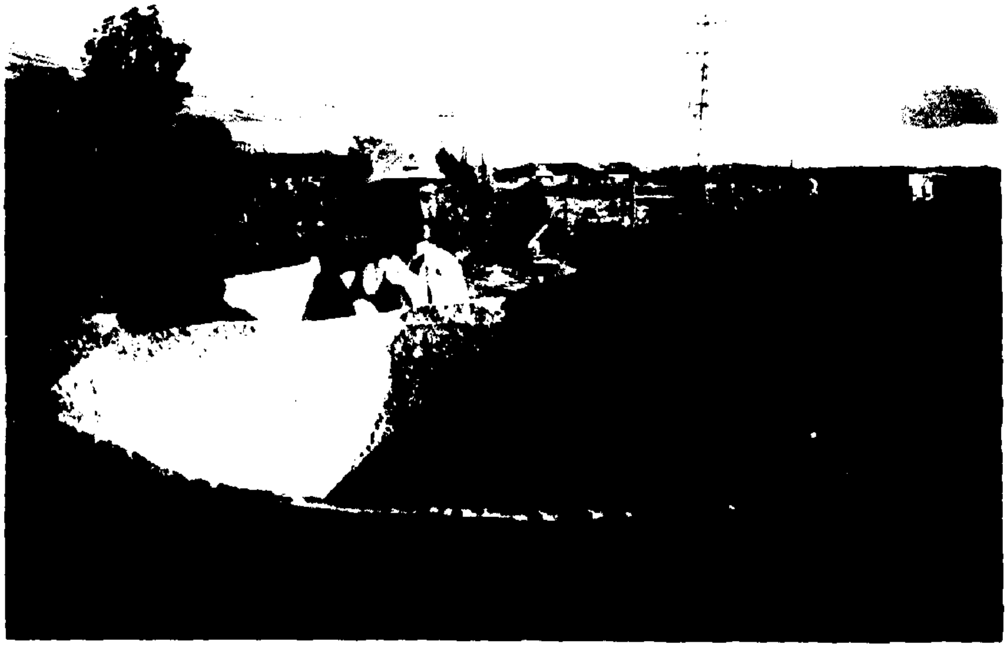

FIGURE 4-3 Damaged Section (Tensile Failure) of 84-inch Diameter Inlet Line at the 550-mgd Water Treatment Plant - Failure Due to Liquefaction and Lateral Spreading of Local Soils

FIGURE 4-4 Typical Six to Eight Inch Settlement of Soils Adjacent to Concrete Basins at the 600-mgd Water Treatment Plant - Settlement Severed Several Buried Electrical Conduits and Chlorine Solution Lines

FIGURE 4-5 Typical Repaired Cracks (by Epoxy Injection and Concrete Patch) in the Los Angeles Aqueduct - Cracks were Primarily Caused by Settlement of Supporting Soils

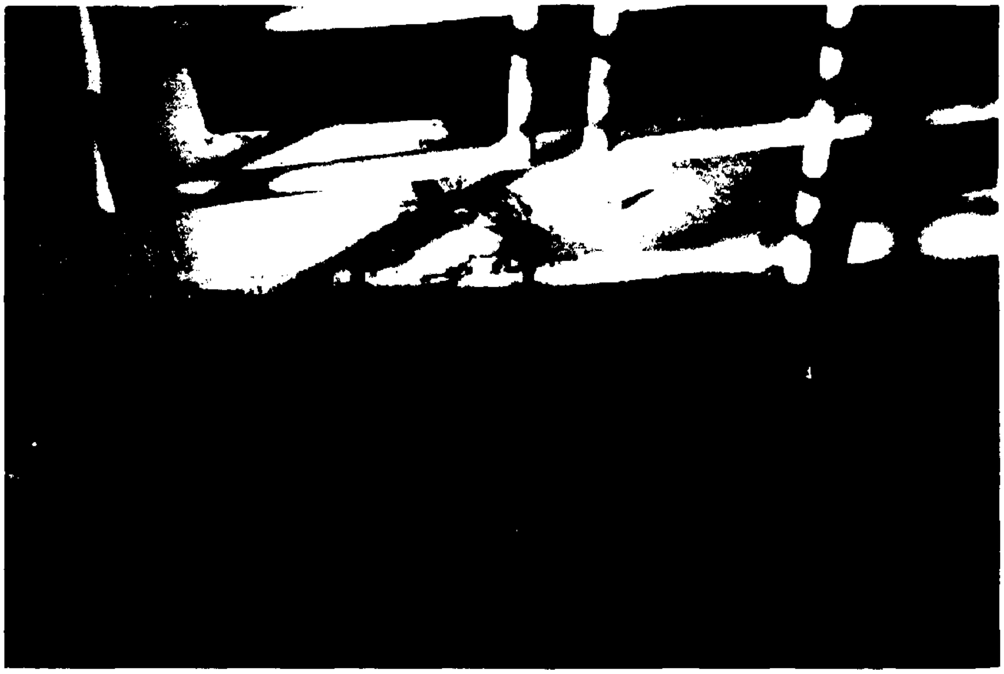

FIGURE 4-6 Typical Repaired Cracks (up to One Inch Wide, by Elastic Sealant) in Concrete Basins of the 600-mgd Water Treatment Plant in the San Fernando Valley

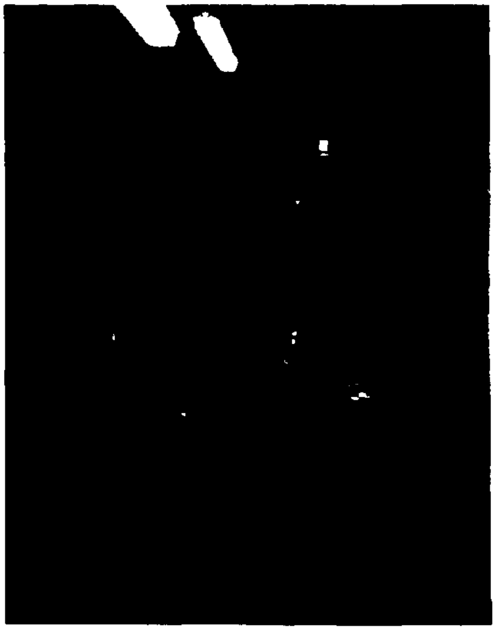

FIGURE 4-7 Utility Gallery in the 600-mgd Water Treatment Plant (Note water leaking out of cracks in concrete basin. Extensive cracking of concrete structures and basins was observed at this facility.)

FIGURE 4-8 Sloshing and Suction Damage to Top of Welded Water Storage Tank in the Santa Clarita Valley - Internal Roof Trusses of this Tank Collapsed

FIGURE 4-9 Elephant's Foot Buckling of Water Storage Tank in the Santa Clarita Valley

FIGURE 4-10 Damaged Welded Water Storage Tank in the Santa Clarita Valley - Rocking of Tank Caused Elephant's Foot Buckling at the Tank Base and Damaged Inlet and Outlet Lines

FIGURE 4-11 Collapsed Bolted Water Storage Tank in the Santa Clarita Valley

The most significant damage to the water distribution pipeline network was within the epicentral area. Preliminary reports indicate that there were over 1,200 leaks in the San Fernando Valley and approximately 300 in the Santa Clarita Valley. Pipes were broken by compression and tension and weakened by corrosion due most likely to vibration and tectonic movement.

The repairs were extremely time consuming. Damaged pipes required draining prior to repair. After the repair, pipes were filled for testing and chlorination and, invariably, additional leaks were discovered requiring a repeat of the process. In a number of cases, this process was repeated many times and was more time consuming in large diameter pipes which required more time to drain and fill.

There was no significant damage to pumping facilities or wells other than loss of commercial power. There was, however, damage to tanks which included inlet-outlet piping, buckling at the bases of tanks (elephants foot), shell buckling, ground settlement and roof damage.

There is an interesting co-location of nine lifelines on Balboa Boulevard in Granada Hills where, beneath the street, there are three gas, three water, two sewer and one oil lines; 34.5kv - 4.8kv per, telephone, and cable TV overhead lines; and ornamental street lighting. Ground movement caused the breakage of some of the underground pipelines, and a fire occurred in the street which ultimately burned the overhead lines and five homes.

Emergency water was provided by bottled water, beer and soft drink beverage companies and water agencies which provided water using rented tanker trucks. Mutual aid brought additional supplies from a dozen water agencies and contractors familiar with water utility work from throughout the state. A number of fire department engine pumpers were used to pump water to high elevation service zones.

Wastewater

There are four water reclamation plants which provide tertiary treatment of wastewater in the epicentral area. Two Los Angeles Department of Water and Power (LADWP) plants (20- and 80-mgd) serve the San Fernando Valley and two Los Angeles County plants (8- and 15-mgd) serve the southern section of the Santa Clarita Valley. All four plants lost power from seven (LADWP plants) to 48 (LAC plants) hours. Emergency power was available in all but the 20-mgd plant, and all started automatically. No biological system loss was experienced in any of the plants. All four plants experienced minor to moderate damage to structures and systems, though none significant enough to hinder operation and affect treatment processes. The most significant damage occurred at the 15-mgd plant and included cracking and leakage in several concrete basins, (see Figures 4-12 and 4-13) and damage to process equipment such as aerators and associated piping, clarifier flights (scappers) and chains, and odor covers (bent downwards from sloshing suction). Basin cracks of up to one half inch (12 mm) and construction joint

FIGURE 4-12 Typical Cracks (up to 1/2 Inch Wide) in Concrete Basins in the 15-mgd Wastewater Treatment Plant in the Santa Clarita Valley

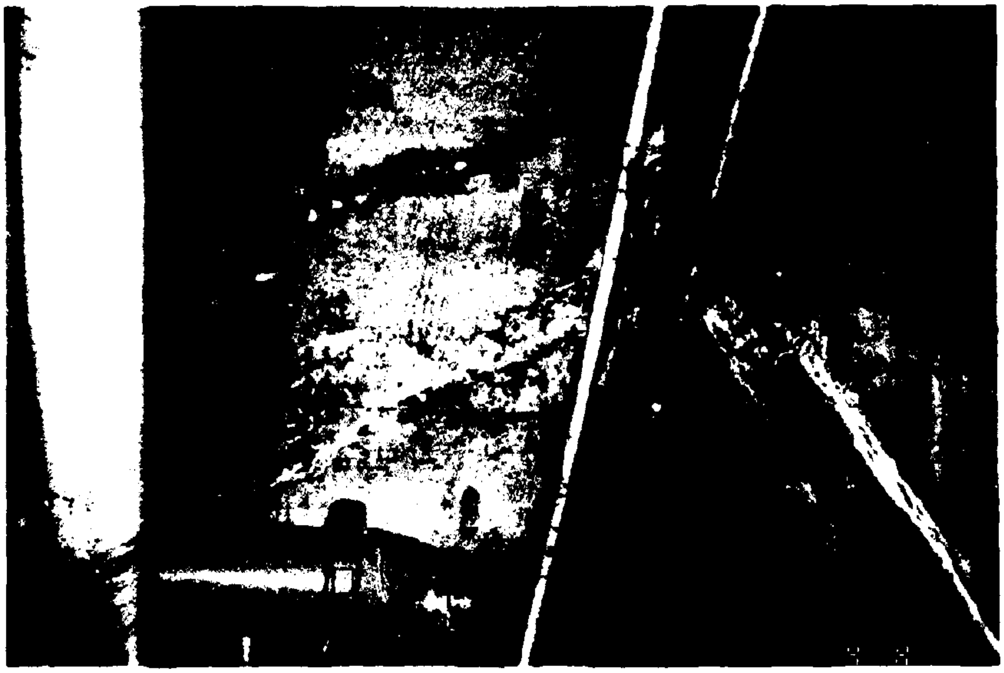

FIGURE 4-13 Repaired Cracks (by Epoxy Injection) in Concrete Basins of 15-mgd Wastewater Treatment Plant in the Santa Clarita Valley

separations of up to one inch (25 mm) led to flooding (about a foot high) in the underground equipment galleries. Damage at the other three plants was signficantly less and consisted of lesser combinations of the damage at the 15-mgd plant.

The collection systems throughout the San Fernando and Santa Clarita Valleys experienced minor damage, and typically included settlement around manholes and cracking of sewer lines. Sewer line cracks typically occurred in clay pipe and included crown (top of pipe) collapses or cave-ins, pushed in sidewalls, and joint misalignments. Following the earthquake, sewer lines in areas of significant structural damage were televised for damage. Over 12 miles of sewer mains were inspected within a month of the earthquake and about four percent were found to be damaged, with about one percent needing immediate repairs (see Figure 4-14).

4.3 Electric Power

About two million electric utility customers in the Los Angeles area awoke to darkness at 4:31 a.m. on Monday morning, January 17, 1994. Damage to substation apparatus supported by brittle porcelain insulators was the primary contributor to power outages throughout Los Angeles and surrounding areas, with black-outs reported in seven Western states and Canada. Service was quickly restored with less than 75,000 customers without power the day following the event and virtually all service restored within one week.

Electrical power systems in the affected areas are operated by the LADWP and Southern California Edison as well as municipal utilities such as the cities of Burbank and Glendale. Most of the generating capacity for the Los Angeles basin is located outside of the earthquake affected region, however, both AC and DC bulk power transmission lines enter the San Fernando Valley within a few kilometers of the epicenter.

Generating stations within the affected region experienced moderate levels of ground motion while several substations and converter stations saw much higher ground accelerations. Earthquake damage to transmission towers, DC converter stations, and substations resulted in widespread local and isolated remote power outages lasting from minutes to several days. Generating stations sustained only minor damage and were generally available for service soon after the earthquake.

Electric Power Transmission

Both AC and DC bulk power transmission lines provide power from remote generating facilities and terminate at a converter station and substations located within a few kilometers of the epicenter. High voltage electrical transmission facilities affected by the earthquake include the Sylmar, Rinaldi, RS-J, RS-U and RS-E, Pardee and Vincent substations. Damage sustained by 230 and 500kv transmission apparatus ranged from substantial to minor depending on the severity of ground motion and seismic design features (see figure 4-15).

FIGURE 4-14 Portable Bypass Equipment (to Bypass Sewage Flow) Used in Support of Televised Inspection of Underground Sewer Lines

FIGURE 4-15 Several Electrical Transmission Towers Failed During the Earthquake - Foundation Distress was Observed at Most of the Failed Towers

Two DC transmission lines provide bulk power to the Los Angeles area from remote power sources. A DC transmission line from the hydroelectric power producing Pacific Northwest terminates near the epicenter at a converter station in Sylmar. The DC converter station sustained significant damage that will disrupt the flow of power for an extended period of time. The second DC line originates at a large coal fired plant in Utah and terminates at a facility in the high desert, unaffected by the earthquake. Transmission system disruptions, however, resulted in an automatic shutdown of the Utah station which provides virtually all of its power to the Los Angeles area. The plant tripped off line due to loss of the Los Angeles area load, contributing to the widespread blackouts.

High voltage transmission stations experienced ground accelerations approaching 1g in both the horizontal and vertical directions, some of the highest free-field ground motions on record. Near field stations experienced damage to porcelain supported power apparatus such as circuit breakers, disconnect switches, lighting arresters, rigid bus, capacitor banks and transformer bushings. Stations located farther from the epicenter which experienced lower ground accelerations, however, sustained damage to historically vulnerable apparatus such as live tank circuit breakers and disconnect switches supported by tall slender porcelain insulators. Damage sufficient to knock several 500kv circuits out of operation occurred at ground accelerations as low as 0.15g.

Transmission stations affected by the Northridge earthquake experienced higher ground motion than during the 1971 San Fernando earthquake, although, due to improvements in design, sustained considerably less damage. Live tank circuit breakers, historically vulnerable and costly to replace, have been replaced by dead tank and bulk oil circuit breakers at most of the substations affected by the earthquake. All of the dead tank and oil filled breakers performed without incident. Seismic instrumentation in-place during the 1971 event was much less extensive than the current array, and failure of several components that survived the 1971 event without damage confirms a more severe seismic environment in the recent event.

Improvements in the seismic design of high voltage substation apparatus since the 1971 San Fernando earthquake resulted in substantially less damage. Improvements such as dead tank circuit breakers and innovative seismic designs such as vibration isolated suspension support systems proved to be effective.

Electric Power Generation

Reconnaissance team engineers visited the Valley Generating Station located near Hansen Dam, the Burbank Power Plant, and the Glendale Power plant immediately following the event (see figures 4-16 and 4-17). The plants are operated by the Los Angeles Department of Water and Power, the City of Burbank, and the City of Glendale, respectively.

FIGURE 4-16 High Voltage Substation Apparatus Supported by Brittle Porcelain Insulators were Damaged at Several Substations

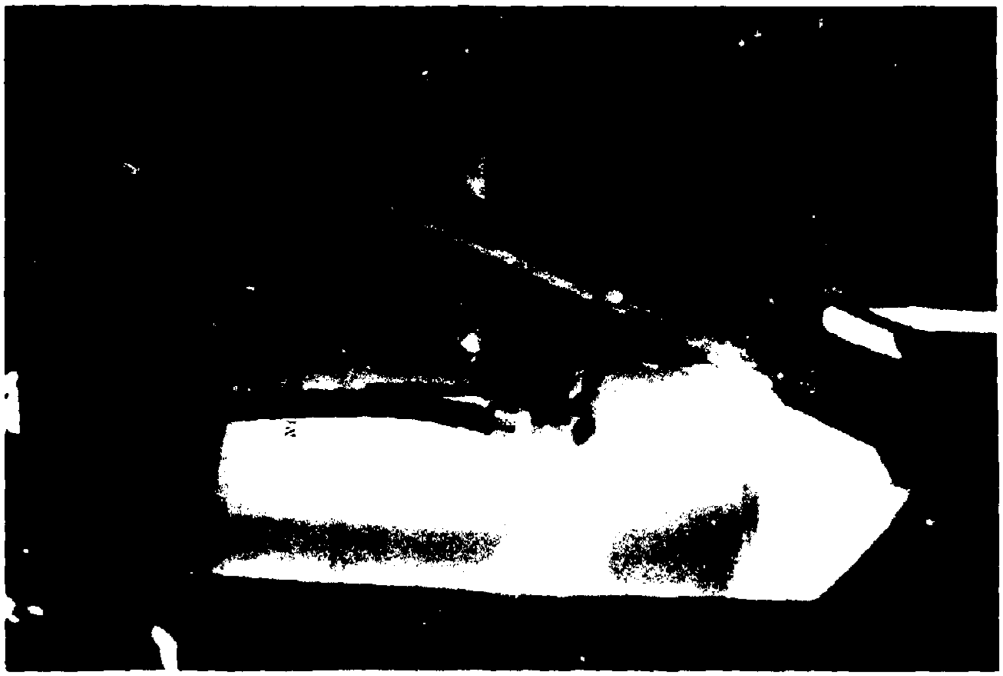

FIGURE 4-17 Electric Generating Plants Sustained Primarily Minor and Cosmetic Damage such as Crushed Piping Insulation due to Movement of Steam Pipes

The Valley Generating Station, located closest to the epicenter, includes two 95,000kw units (Units 1 & 2) that are currently not operational and two 160,000kw units (Units 3 & 4) that were on cold-standby when the earthquake occurred. Preliminary strong motion data and damage assessments indicate that the facility experienced about the same level shaking as experienced during the 1971 San Fernando earthquake, approximately 0.4g horizontal peak ground acceleration. The facility sustained minor damage such as cracks in steel struts, a twisted wide flange, distorted exhaust duct insulation panels, damaged piping insulation, inoperable combustion air instruments, leakage in a welded condensate line, and superficial damage to building elements. Numerous relays had to be reset prior to restart. The damage did not prevent plant operation and Units 3 & 4 were successfully brought on-line several hours after the earthquake. The plant continues to supply power to the region.

The Burbank power plant consists of two facilities, the five unit Magnolia Plant and the four unit Olive Plant. At the time of the earthquake only two units were running and one unit was on hot standby. All units tripped off line due to fluctuations in the power grid. Damage and failures were limited to a broken PVC line, spalling at tank footings, failure of small diameter pipes, deformation of tank anchor clips, and damage (not failure) to a crane. Combustion turbine units were brought on-line soon after the earthquake followed by steam units.

The Glendale Power Plant has five natural gas fired boilers ranging from 20,000 to 44,000kw and several smaller gas turbines. Two units were running at the time of the earthquake and tripped off-line upon fluctuations of the power grid. Damage and failures included bearing damage due to loss of lube oil, rupture of 24 inch (610 mm) diameter cooling tower inlet risers, and superficial damage. Power to the facility was restored on the morning of the earthquake and units, excluding Unit 5 pending bearing inspection, were brought on line on an as-needed basis soon thereafter.

4.4 Gas Delivery Systems

The natural gas system in the Los Angeles metropolitan area is owned and operated by the Southern California Gas company. It is the largest U.S. gas system in terms of customers, with approximately 4.6 million metered services. According to company statistics compiled for 1993, there are 3,803 miles (6,123km) of steel transmission pipelines and 26,809 miles (43,162km) and 14,935 miles (24,045km) of steel and plastic distribution mains, respectively. The transmission pipelines are predominantly eight to 36 inches (200 to 900mm) in diameter and operated at pressures generally exceeding 150psi (1MPa). The distribution system is composed of pipelines of two to twelve inches (50 to 300mm) in diameter and limited to pressures of 60psi (0.42MPa) or less. The plastic piping is made of either medium or high density polyethylene.

There were approximately 148,000 gas outages as a result of the earthquake, of which 123,000 were customer initiated. Service was restored to approximately 84,000 customers within one week of the earthquake, and to almost 120,000 within one month of the event. Service cannot be restored to 9,100 customers because of structural property damage.

Two months after the earthquake, approximately 624 repairs had been made to distribution mains and services. There were 394 repairs to metallic piping with evidence of corrosion, and 197 repairs in steel mains and services with no corrosion observed. There were 36 repairs in polyethylene pipes, the majority of which were at couplings and transition fittings.

There were 35 non-corrosion related repairs in the transmission system, of which 27 were at cracked or ruptured oxy-acetylene girth welds in pre-1932 pipelines. Two repairs were made on a 12 inches (300mm) transmission pipeline at locations of corrosion. Figure 4-18 shows a plan view of selected transmission pipelines in the area of most severe ground shaking. Locations of damage in the form of pipeline breaks and leaking flanges are shown in the figure. There were 25 breaks at oxy-acetylene girth welds in Line 1001 which conveys gas between Newhall and Fillmore, many of which were in Pico and Potrero Canyons. Line 1001 was constructed in 1925, and was operated at the time of the earthquake at about 245psi (1.7MPa) internal pressure. Gas escaping at the location of a break in Line 1001 under Highway 126 near Fillmore was ignited by a downed power line, and the ensuing fire burned a mobile home in an adjacent trailer park.

Figure 4-19 is a map of the area just north of the earthquake epicenter, showing the Aliso Canyon Gas Storage Facility and the locations of two gas transmission line breaks on Balboa Boulevard. The Aliso Canyon facility, which covers some 3,600 acres and 35 mi. (56km) of access road, is used to store gas in an underground reservoir, which once was used primarily for oil production. Gas is injected during low demand summer months and withdrawn during high demand winter months. Earthquake effects at the facility included deformation of above-ground pipe supports, displacement of runs of injection and withdrawal lines, and structural damage to a fin fan unit used to cool compressed gas before its injection in storage wells. The supply of gas from Aliso Canyon was interrupted for five days.

As shown in Figure 4-18, there was a break in Line 104 inside the storage field. The line was ruptured by landslide movement at an overbend. The line was 10 inches (250mm) in diameter, operated at about 200psi (1.38 MPa) and was constructed in 1941.

Three water tanks in the facility were damaged. The tank supplying water to the main plant was not damaged, but pipelines conveying water from the tank developed leaks, thereby cutting off supply. Of approximately 12 oil storage tanks at the facility, five were damaged. As shown in Figure 4-20, one tank collapsed and another at the same location sustained a split seam. Damage at other oil storage tanks was relatively minor and consisting of buckling and warping of steel plates. The fuel gas system used for heaters and plant instruments was disrupted in several locations. A number of transformers fell from poles, disrupting electrical service.

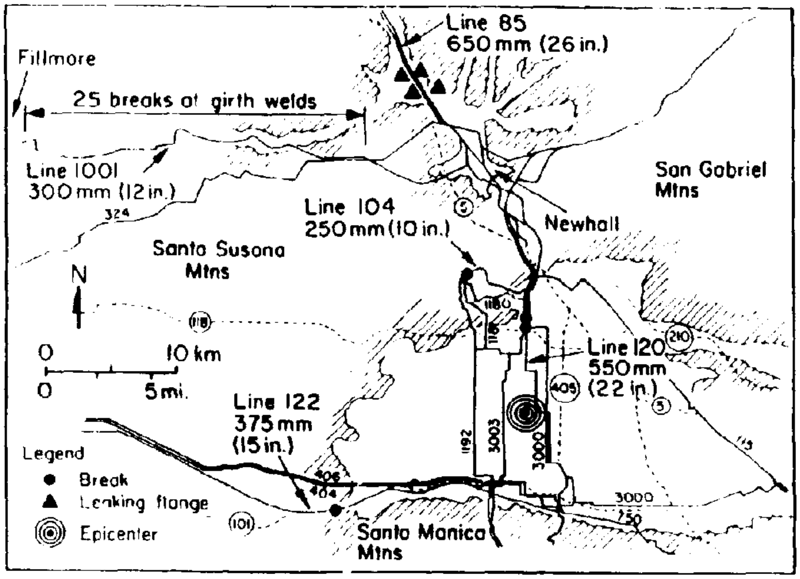

FIGURE 4-18 Map of Gas Transmission Pipelines in the Area of Strong Ground Shaking

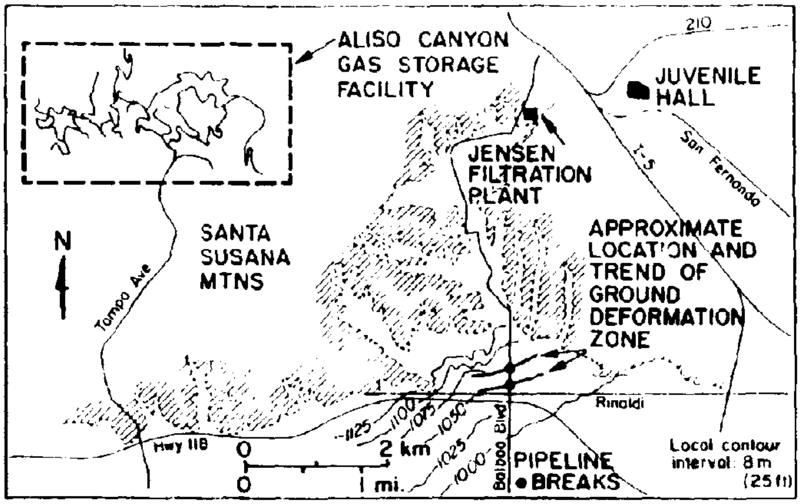

FIGURE 4-19 Map of the Area North of the Northridge Earthquake Epicenter

Due to failed water tanks and associated piping damage, water supply inside the facility was disrupted. Because of damage to LADWP trunk and distribution mains, water supply from outside the facility also was disrupted. Vacuum trucks were dispatched to locations of leaking trunk lines outside the facility where water was collected and brought back for internal use.

There were numerous landslides throughout the facility. Figure 4-21 shows a landslide of approximately 500 yd^3 ($380m^3$) which undermined an injection line near the top of the slope. Debris from the slide caused deformation of two withdrawal lines and an injection line which are located adjacent to the roadway shown in the photograph. The landslide was typical of ground displacements in many parts of the facility. The slide was activated along joints dipping at approximately 60° subparallel to the slope. The rock is friable sandstone of the Topanga Formation.

With the exception of a leaking flange in an area of slope movement, there were no leaks or ruptures of above ground withdrawal and injection pipelines. Serious damage to above ground pipelines was scarce, even though there were many deformed pipe supports and sections of line undermined and distorted by local landslides. The presence of large ground cracks and the potential for further ground movement are likely to require continuing remedial action to stabilize slopes and protect vulnerable pipes.

Gas pipeline damage on Balboa Boulevard occurred in Line 120, a 22 inch (550mm) diameter steel pipeline constructed in 1930 with unshielded electric arc girth welds. At the time of the earthquake, the line was operated at about 175psi (1.2 MPa). The pipeline failed in tension in a zone of tensile ground deformation about 1,000 ft. (330m) north of a zone of compressive ground deformation where the pipe failed by compressive wrinkling. As shown in Figure 4-19, the ground rupture zones occurred in the toe area of an alluvial fan and are oriented subparallel to the surface elevation contour lines. This pattern of ground deformation suggests that lateral spreading of the alluvial fan sediments took place. Nearby boreholes show loose silty sands at depths of 30 to 40 ft. (9 to 12m), although water levels are indicated at considerably greater depths in dense materials.

Figures 4-22 and 4-23 show maps of the pipelines in Balboa Boulevard near the zones of permanent ground deformation. In addition to numerous distribution mains, there were six transmission and water trunk lines at this site. There were two 30 inch (750mm) diameter gas transmission lines constructed of X-52 steel in the 1950s which were not damaged. There was a 16 inch (400mm) diameter petroleum pipeline, operated by the Mobil Oil Corporation, which was not damaged. The pipeline was composed of X-52 steel and installed in 1991. Two water trunk lines, the 49 inch (1,240mm) diameter Granada and the 68 inch (1,730mm) diameter Rinaldi Trunk Lines, failed in tension and compression in the tensile and compressive zones of ground deformation, respectively.

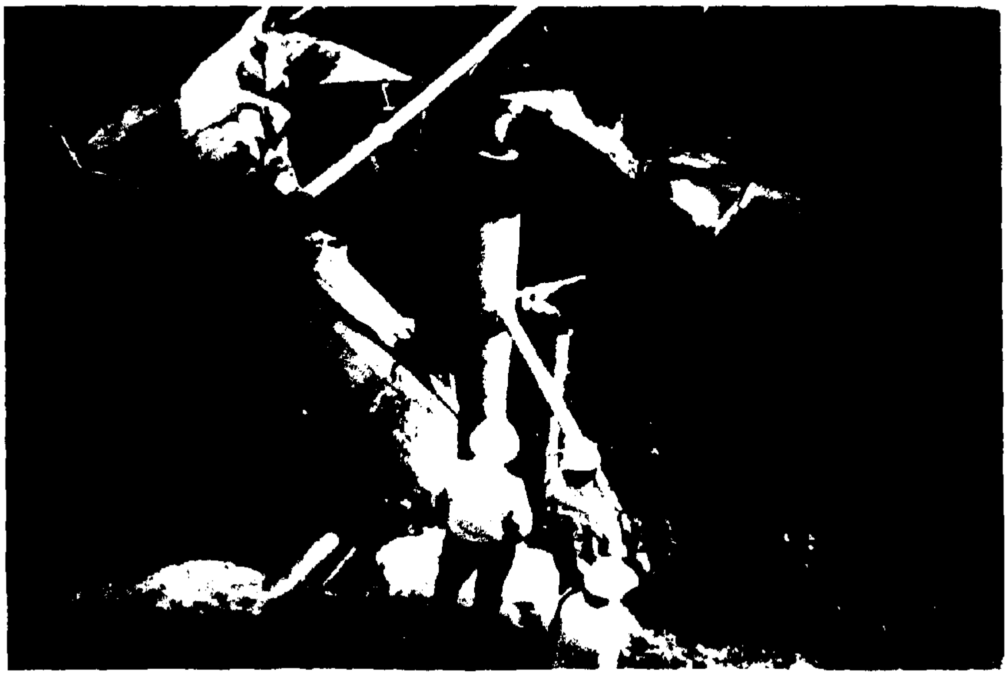

FIGURE 4-20 Collapsed Oil Tank in the Aliso Canyon Gas Storage Facility

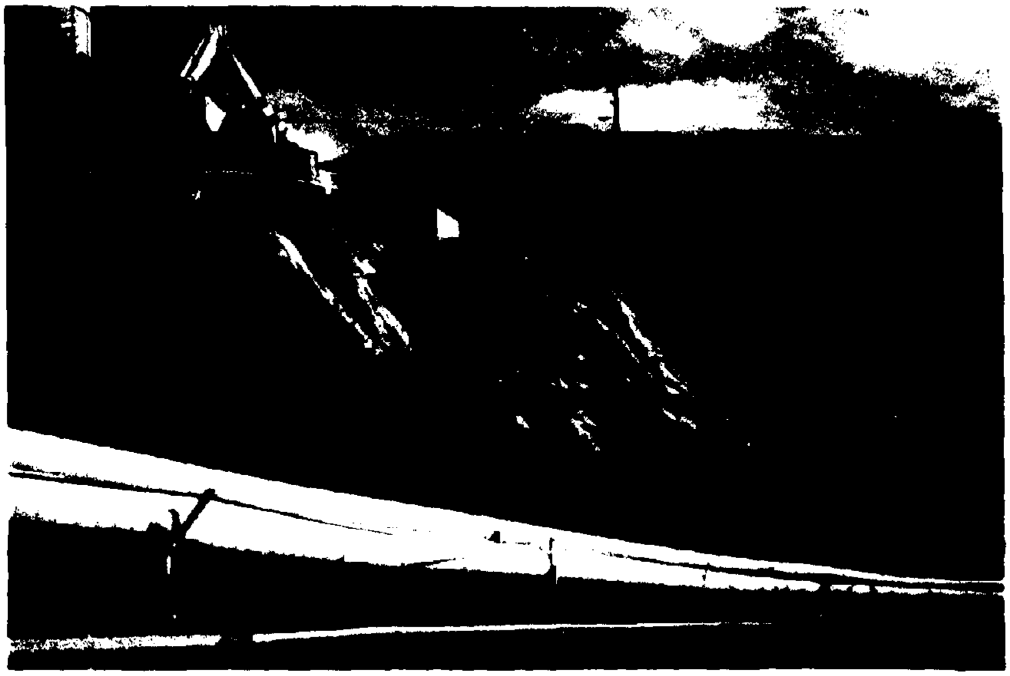

FIGURE 4-21 Local Landslide in Sandstone and Overlying Soil at the Aliso Canyon Gas Storage Facility

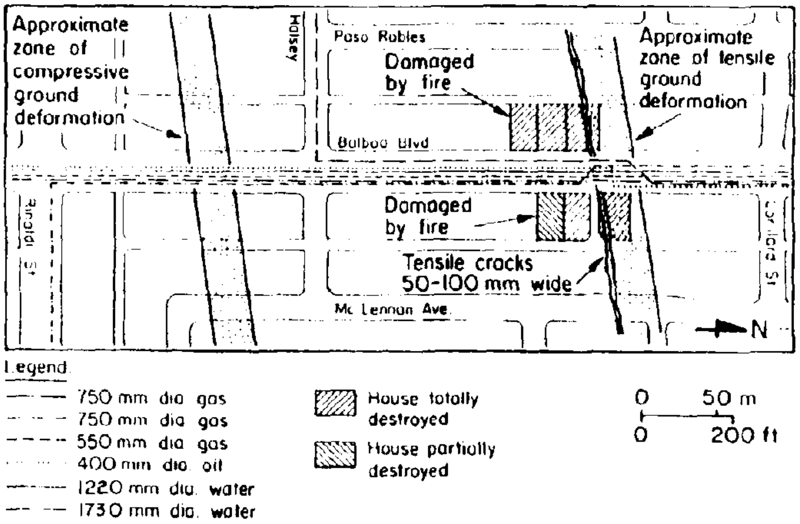

FIGURE 4-22 Map of Major Pipelines, Fire Damage, and Ground Deformation Zones on Balboa Boulevard

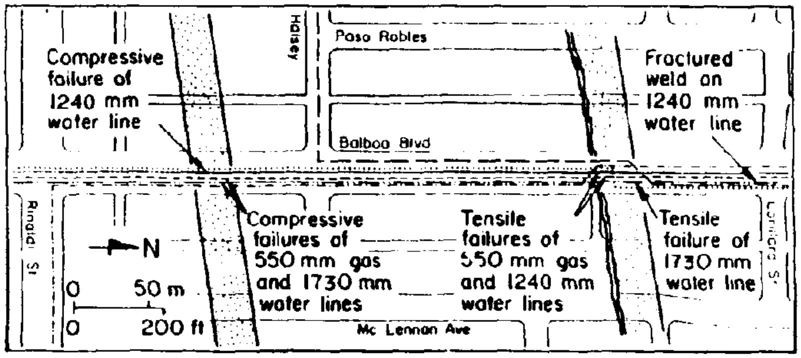

FIGURE 4-23 Map of Major Pipelines, Ground Deformation Zones, and Locations of Pipeline Damage on Balboa Boulevard

Figure 4-24 shows a view during repair of the Granada Trunk Line and Line 120 in the zone of tensile ground movement. Figure 4-25 shows a compressive failure of the Granada Trunk Line in the zone of compressive ground deformation. The deformation is typical of compressive failures in both trunk lines. The welded slip joint was buckled and split in tension near the top of the pipe. Figure 4-26 shows tensile ground cracks in cementitious backfill covering the Mobil Oil pipeline in the zone of tensile ground deformation. Two prominent cracks, each two to three inches (50 to 75mm) wide, can be seen in the photo.

Gas escaping from Line 120 was ignited by sparks from the ignition system of a pick-up trunk, which had stalled in the area of tensile ground deformation flooded by the ruptured trunk lines. The gas fire spread to adjacent properties, destroying five houses and partially damaging an additional structure.

There was damage in the Honor Ranch Storage Facility near Newhall, although the earthquake effects at this installation were considerably less than those at Aliso Canyon. There was disruption of the fire loop system, brine filtration equipment, and access roads. A 16 inch (400mm) diameter water main, water tank, gas piping, and electrical transformer also were damaged.

Although direct comparison of gas system performance for two different earthquakes is not possible because of differences in seismic intensities and composition of the system, it nonetheless is useful to review overall performance in 1971 and 1994 so that the relative scales and changing patterns of response can be approximated. After the 1971 San Fernando earthquake there were over 100 breaks in gas transmission lines, primarily in the San Fernando and Sylmar areas. The relatively low numbers of transmission line leaks and breaks in 1994 is related in part to the replacement or retirement of pre-1932 oxy-acetylene welded pipelines. After the 1971 San Fernando earthquake, for example, approximately 12 miles (19km) of Line 1001 were abandoned in the San Fernando area. In 1994, remaining portions of the same line suffered breaks in oxy-acetylene girth welds between Newhall and Fillmore.

In 1971, there were approximately 380 breaks of predominantly steel piping and related services in the San Fernando and Sylmar communities, and supply was lost to 17,000 customers. Incidents reported as a result of the Northridge earthquake account for damage to 624 distribution mains and services. The leaks reported after the earthquake disclose a broad pattern of response to combined seismic and corrosion-related effects.

4.5 Oil Pipelines

Oil pipelines in the epicentral region primarily serve to transport crude oil from production facilities north of the epicentral region to refinery facilities to the south. The only known case of damage at the time this report was prepared occurred to the Four Corners Pipeline Company's Line No. 1. This 10 inch (254mm) pipeline, built in 1926 with oxy-acetylene welded joints, is

FIGURE 4-24 Damaged Water Trunk and Gas Transmission Pipelines at the Zone of Tensile Ground Deformation and Fire on Balboa Boulevard

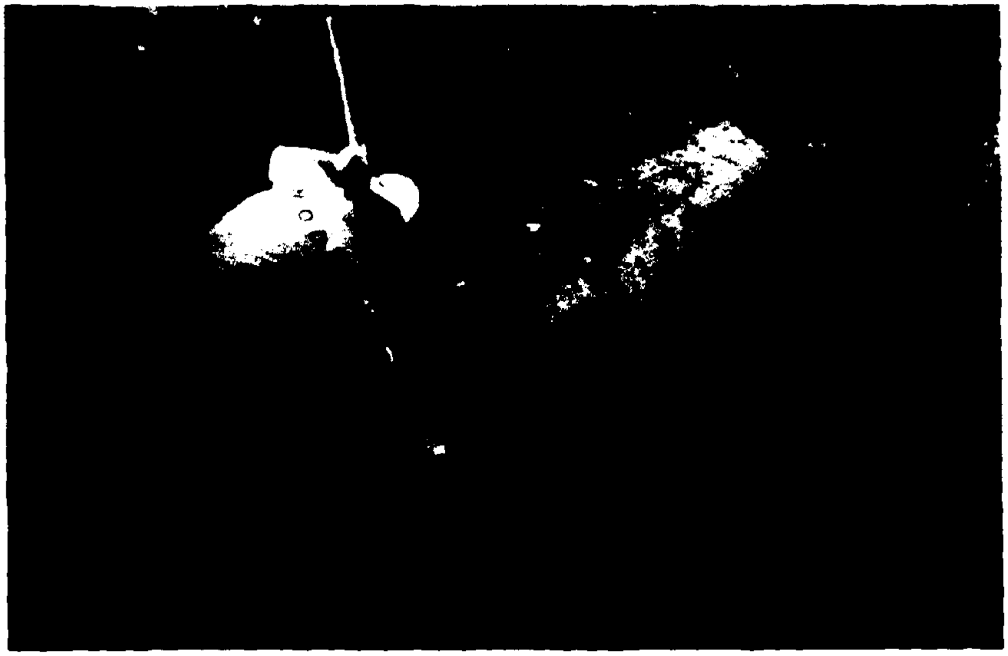

FIGURE 4-25 Compressive Failure of a Welded Slip Joint of the Granada Trunk Line on Balboa Boulevard

FIGURE 4-26 Subsurface Cracks at the Zone of Tensile Ground Deformation on Balboa Boulevard

one of the oldest in operation by Four Corners Pipeline Company and is used to ship oil from the San Joaquin Valley to the Los Angeles area.

The pipeline suffered eight breaks at girth welds, all within 20 miles of the epicenter. The pipeline was not operating at the time of the earthquake and oil spillage was limited to that which could drain from the pipeline under gravity flow. Two locations of damage to Line No. 1 had the most serious consequences. Damage near the Newhall pumping station reportedly caused approximately 3,000bbl of oil to drain into the Santa Clara River. Oil leaking from a damaged pipe in the vicinity of Wolfskill Street in a residential area of San Fernando caught fire. Although there was only one injury, the fire burned four houses and 17 cars.

Other damage to Four Corners Pipeline Company's Line No. 1 was located along I-5 adjacent to the Valencia golf course, the Placeritas pumping station and in Posey Canyon near Pyramid Lake. Permanent ground deformation at the Placeritas pumping station is the suspected cause of oil line damage as well as nearby damage to water lines and a 12 inch (300mm) natural gas line. The most distant damage to Line No. 1 was also reported in Posey Canyon near Pyramid Lake.

Line No. 63 operated by the Four Corners Pipeline Company runs through areas seriously impacted by the earthquake. No damage occurred on this 14 inch (355mm) arc-welded pipeline. Chevron, Texaco, Mobil Corp. and Shell Oil Co. also operate pipelines in the areas most affected by the earthquake. These pipelines were shut down following the earthquake as a precaution and no damage has been reported.

One Mobil Corp. oil pipeline runs along Balboa Boulevard adjacent to two pressure water trunk lines and two moderate pressure natural gas pipelines. The water lines and one gas line suffered damage as a result of permanent ground deformation. The Mobil 16 inch (400mm) pipeline is of recent vintage and was exposed in the east side of the excavation to repair the 68 inch (1,730mm) water trunk line. Immediately south of that excavation, the oil pipeline turns 90° to the west for approximately 20 to 30 feet (6 to 10 meters) and then turns 90° to the south to continue along Balboa Boulevard. At this location, the cement slurry used to backfill the Mobil pipe formed the west wall of the crater eroded by the rupture of another water trunk line (see Figure 4-14). This is also where a tensile failure occurred to the 22 inch (550mm) natural gas pipeline. A slight bowing of the oil line observed during repairs to the water and gas pipelines seemed to indicate a slight residual compressive load that may have been related to ground deformation in the area.

The behavior of the oil pipelines in the Northridge earthquake is consistent with past experience. In the absence of extremely rare soil conditions, pipeline damage in earthquakes is associated with permanent ground deformation. Older steel pipelines fabricated with oxy-acetylene welded joints are much more vulnerable to ground deformation. The growing prevalence of lean cement backfill materials was evident during the recovery from this earthquake. Some future investigation may be desirable to understand what impact this practice may have on pipeline response to permanent ground deformations.

SECTION 5
NONSTRUCTURAL BUILDING ELEMENTS

Nonstructural building elements are those components and equipment that are not part of the structural lateral force system but are subject to the building dynamic environment caused by an earthquake. The entire range of architectural, mechanical, electrical, communication, and elevator components is included. Occupant supplied contents and furnishings are also considered nonstructural elements. Depending upon the building occupancy (commercial, residential, industrial, educational, institutional, public, etc.), the nonstructural components can represent 40-80% of the facility's replacement cost. Within each group of components, there is great diversity of types and sizes making it difficult to categorize nonstructural components in a consistent manner for post-earthquake damage reviews.

Current building code requirements for seismic restraint and anchorage of nonstructural components in commercial buildings are based on the premise that damage is to be expected at a moderate level of earthquake ground motion. For structures subject to considerable structural damage, only life-safety is presumed to be maintained. Thus, the nonstructural elements are sacrificial in normal commercial construction with a somewhat vague performance requirement that life-safety should be maintained.

Given the large area subjected to strong ground motion in the earthquake, a focused review of nonstructural damage is not feasible. This review will concentrate on eight common types of nonstructural damage observed during reconnaissance: ceiling systems, secondary water damage, cladding and facades, warehouse racks, hospital nonstructural damage, glass breakage, roof and ground mounted equipment, and contents.

5.1 Ceiling Systems

Suspended Acoustic Ceilings

Suspended acoustic ceilings with drop-in light fixtures is the dominant ceiling system used in commercial and institutional buildings. As a nonstructural element, these ceiling systems illustrate many of the issues associated with nonstructural performance in earthquakes.

In 1976, the installation requirements for suspended acoustic ceilings were modified to include splay wire bracing. Requirements for an additional vertical strut were added in 1980. In addition, a minimum test strength for the tee-bar grid connections was specified and all light fixtures supported by the grid were required to have independent safety wires. These requirements were a direct result of the ceiling damage experienced in the 1971 San Fernando earthquake.

Within the San Fernando Valley, a wide range of ceiling vintage is present, ranging from pre-1976 ceiling installations to ceilings just recently installed. It should be noted that the commercial and retail ceilings in the northwestern San Fernando Valley are a mix of newer installations combined with those that are approximately 20 or more years old, having been replaced after the 1971 earthquake. This diversity of ceiling vintage makes it difficult to generalize about ceiling performance. While the dropping of acoustic tile was widespread, it does not appear that the falling of light fixtures (without safety wires) was also widespread (see Figure 5-1). This may be due to the shorter duration and increased vertical character of the strong ground motion.

In large retail stores (e.g., markets and drug stores) of approximately 50,000 square feet (4,650m^2) where clip-on type open tube fixtures are utilized, light tube falls occurred (about 10-15%). Perimeter damage with occasional grid drops was also common and ceilings with unbraced vertical breaks had more damage. In commercial buildings with individual offices and floor-to-ceiling partitions, ceiling damage was less frequent.

For ceilings installed under current code requirements, the presence of a vertical strut in splay wire brace does not limit ceiling lateral displacement and may result in the same level of perimeter damage as with splay wires only. In some instances, attachment of the ceiling to a wall angle has become the defacto ceiling brace bypassing the more flexible splay wire braces.

An acoustic ceiling is a low-cost, replaceable building finish system, thus, the instances of ceiling damage observed in this earthquake may be judged acceptable. Falling metal light fixtures (in a few instances, safety wires failed) are a potential life-safety issue and cannot be considered acceptable. Since a large fraction of the total ceiling square footage within the existing building stock is pre-1976, the retrofit installation of fixture (including HVAC diffusers) safety wires is a simple cost effective safety measure that should be considered.

Other Ceiling Systems

Drywall ceilings appeared to have performed quite well in the Northridge earthquake. Despite some repairable cracking, their relative lightweight and positive connection to the framing system above tended to preclude major damage.

However, there were several instances of heavier materials, such as plaster and stucco ceilings, completely detaching from their framing systems. This was most evident in outdoor covered walkways in public areas, such as shopping centers (see Figure 5-2).

Several stucco ceilings completely peeled away in large sheets, falling to the ground. This was due to poor connection of the lathe to the framing system. Had the earthquake occurred during the day, this could have seriously injured pedestrians.

FIGURE 5-1 Typical Post-Earthquake Suspended Ceiling

FIGURE 5-2 Stucco Breezeway Ceiling Detached from Concrete Frame at the Northridge Fashion Center

5.2 Secondary Water Damage

General

Secondary water damage from broken plumbing and fire sprinkler piping was a common occurrence in all types of structures and is expected to account for a large portion of the total cost associated with the earthquake. The sources of water were many and varied: roof mounted tank failures, chilled water line failures in building HVAC penthouses, domestic water supply lines, heating water lines (especially at connections to HVAC duct coils), and sprinkler line leaks, breaks, or inadvertent activation.

Water and sanitary drains were also dislodged and broken, resulting in water damage from post-earthquake use. In some cases, additional water damage occurred due to a post-earthquake rainstorm, especially in buildings in which roof drain piping had been dislodged by the earthquake.

Fire Sprinkler Systems

The Northridge earthquake is the first event in which the sprinkler systems in large square footage buildings have been subjected to such high levels of earthquake ground motion. In some instances, support failures allowed sprinkler piping to fall. The current National Fire Protection Association (NFPA) seismic requirements should be reevaluated and the use of flexible connecting lines encouraged to allow for differential motion between the sprinkler system components.

The earthquake provided performance data for a broad range of sprinkler systems varying in vintage, piping type, and bracing configurations. Older systems may consist of steel pipe with threaded connections and typically exhibit limited bracing. Newer installations have main connections with some flexibility and, as a minimum, include transverse bracing of mains.

The observed damage in older installations with limited or no lateral bracing can be attributed to threaded connection failure due to excessive displacements and/or interaction with adjacent items. Newer systems, although generally braced, suffered costly damage resulting from interaction with unbraced suspended ceilings (see Figure 5-3). The failure typically occurred at the threaded pipe connection above sprinkler head ceiling penetration.

Most of the major department stores in the Northridge Fashion Center experienced severe interior damage. Tiles in unbraced suspended ceilings were dislodged breaking sprinkler pipes which resulted in severe water damage to store inventory below. A significant percentage of inventory and merchandise is a total loss as a result of water damage caused by apparent ceiling movement.

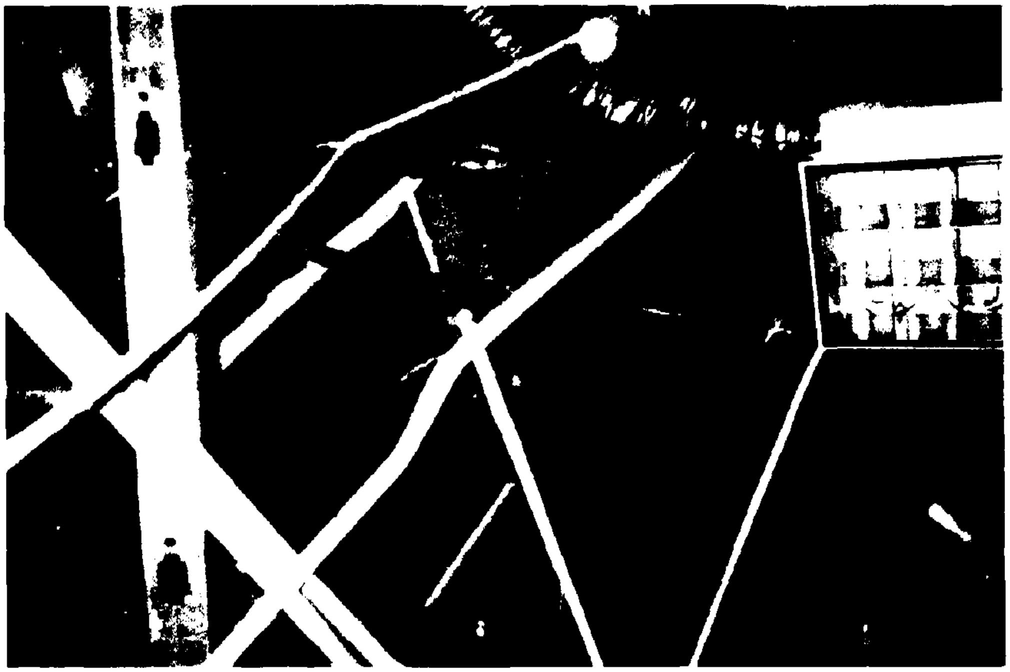

FIGURE 5-3 Broken Fire Sprinkler Head (Riser Connection) due to Interaction with Suspended Ceiling at a Department Store in Los Angeles

Modern high-rise steel frame structures such as those in Warner Center and in Woodland Hills appeared to have performed well. Limited nonstructural damage was reported. However, pneumatically installed shot-pins at vertical sprinkler pipe hangers failed, severing the branch lines and causing water damage to the floors below. A major high-rise hotel at the Trillium Complex in Warner Center appeared structurally intact, but remained closed for several days due to interior damage in the banquet rooms from broken sprinklers.

A vast low-rise industrial park stretches for miles west of the Northridge Fashion Mall. Many buildings house offices and high technology operations. Many of these buildings suffered serious interior damage as evidenced by piles of water drenched ceiling tiles lying on the pavement in front. The Hughes Aircraft and Rocketdyne in Canoga Park and Lockheed facilities in Burbank were shut down for several days due to water damage from broken water pipes.

5.3 Cladding Systems and Facades

Nonstructural cladding systems can be defined as the exterior "skin" of a building, which is not part of the structure's vertical or lateral force-resisting system. Instead, it is attached or "hung" from the building's structural system.

Nonstructural cladding can range from lightweight systems, such as glass and metal panels, to heavy systems, such as precast concrete panels, granite, brick veneer, and marble. One attribute virtually all cladding materials share is that they are rigid. Thus, there is a fundamental problem between these rigid cladding systems, and the more flexible structural system of a building.

Well-designed cladding systems provide gaps between panels to allow movement of the structural system while avoiding contact between adjacent panels. Damage to cladding occurs due to:

- Inadequate gaps between panels. Minor problems include spalling at the contacting edges of heavy cladding, such as precast concrete and stone-type units. Major problems include damage to connections, leading to catastrophic failure of the panel. Both scenarios were evident in the Northridge earthquake, even to fairly new buildings.

- Poorly designed and/or constructed connections. This condition affects lightweight panels as well. A building deflecting laterally may "pop" the connections of light materials, such as metal panels, by imposing higher forces than their design capacity. Light metal buildings lost many such panels in the Northridge earthquake. Older brick veneer buildings were shown to have highly vulnerable connections, leading to detachment of the brick.

Heavy concrete facades are frequently used in building construction for shading or architectural continuity, particularly in buildings with deep window-setbacks. The connections of these facades to the structure often provide weak anchorage. The vulnerability of non-ductile connections was demonstrated in the Northridge earthquake as shown in Figure 5-4.

5.4 Warehouse Racks

The earthquake affected area contains a multitude of low rise warehousing facilities. A majority of these buildings were built during a period of growth which occurred after the 1971 San Fernando earthquake. Consequently, warehousing systems observed are typically of late 1970's and 1980's vintage.

Typical warehouse pallet racks are constructed of upright frames connected by beams. Each frame consists of cold-formed steel posts and diagonal bracing members. Bracing connections are usually welded. The beams fit into pre-punched slots in the posts. Some systems include locking devices to prevent beams from dislodging. Each post is supported on a steel base plate which ideally should be anchored to the concrete slab. Rows of racks can be arranged in twos, threes, or more. Such parallel rows are usually connected between the inner columns.

The lateral loads perpendicular to the aisle (transverse direction) are resisted by the braced frames. Overturning loads are resisted by the base plate and anchors. Lateral loads parallel to the aisle (longitudinal direction) rely on "moment-frame" action of beams and columns. The critical items are:

- Base plate and anchorage
- Distribution and unit weight of pallet loads
- Quality of welds
- Slenderness of bracing member and posts.

Following the 1971 San Fernando earthquake, the standards governing the lateral load design of pallet racks were revised, and today the rack design is based on Uniform Building Code (UBC) Standard No. 27-11 which is patterned on the Rack Manufacturers Institute (RMI) latest recommendations. The design lateral loads are generated in a manner similiar to those for multi-story buildings. However, relatively little guidance is given for member and connection design and the cited UBC standard should reference UBC Chapter 27 for detailed design provisions.

The observed instances of poor rack performance during the Northridge earthquake can be attributed to the following: (see Figure 5-5)

- Poor base plate design and weak anchorage
- Poor warehousing practice
- Lack of system redundancy due to poor detailing

FIGURE 5-4 Failure of Concrete Facade Anchorage Details

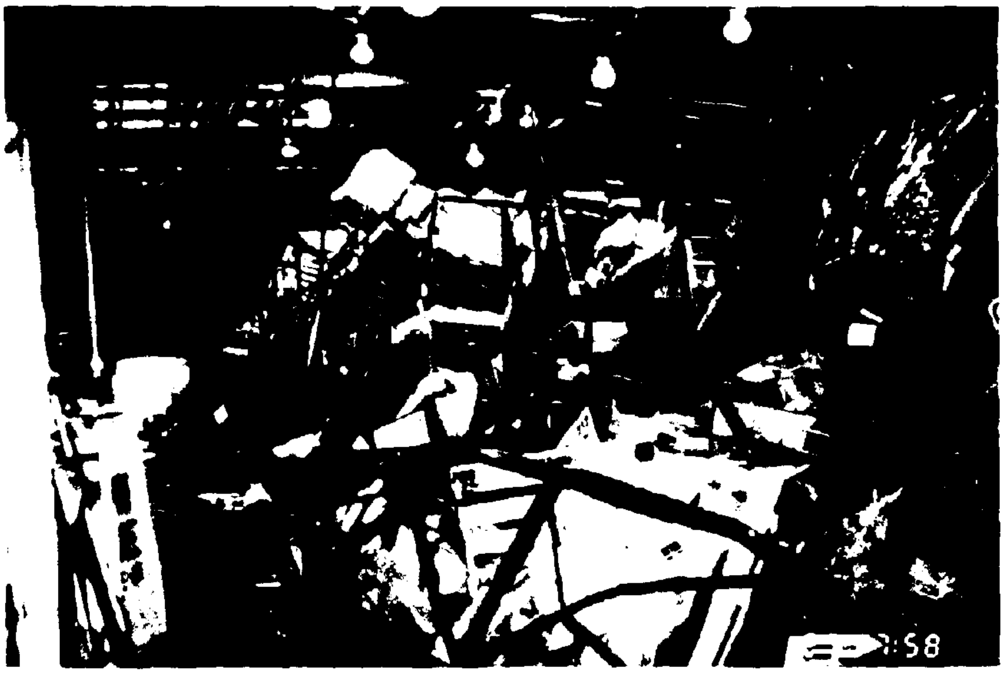

FIGURE 5-5 Collapse Of Warehouse Racks In Santa Monica

A 55,000 square foot tilt-up warehouse in Santa Monica built in 1971 barely survived the failure of the warehouse pallet racks inside. The failure appears to have initiated in column base plate welds in two multi-bay rows which toppled over and knocked out 40% of the racks. The welds between the cold formed steel posts and 3/16 inch thick base plates unzipped leaving the 1/2 inch diameter anchor bolts mostly intact. The building appeared to maintain its integrity with the racks leaning against the columns. The racks were at about 60% of their design load. Many bracing members in the upright racks were buckled.

Rack performance in wholesale "club" stores was directly related to the quality of warehousing practice. Much less rack or inventory damage was observed in stores where pallet load limits were observed, unopened pallets were shrink-wrapped, and heavy items were stored along the lower tiers. On the other hand, overloaded racks with loose, haphazard inventory resulted in severe rack damage and high inventory losses.

5.5 Hospital Nonstructural Damage

Within the region of strongest ground motion, several major hospitals and medical centers were forced to curtail their services and evacuate patients. Among these were:

- Olive View Medical Center
- Holy Cross Medical Center
- Granada Hills Community Hospital
- Northridge Hospital Medical Center

None of these hospitals had serious structural damage (in some cases, administrative buildings were damaged), however, they were forced to close due to nonstructural damage. Within the city of Los Angeles, the loss of Holy Cross and Northridge Medical Centers was particularly acute, since these facilities are the local trauma centers as well as paramedic base stations. Paramedics were forced to transport earthquake victims to more distant medical facilities and to compound existing problems, the primary hospital radio communication network failed, forcing reliance on ham radio operators. The hospital internal telephone systems remained functional, but external telephone communication was not possible due to telephone system tie-ups. All of these facilities set up emergency treatment areas outside for walk-in victims.

Olive View Medical Center

This facility replaced the hospital of the same name badly damaged during the 1971 earthquake. The six-story structural system was functional with minimal damage, despite ground motion of 0.9g and greater at the site. This facility was rendered nonfunctional due to water damage: two chilled water lines broke in the roof penthouses, heating coil connections broke on all floors, and numerous fire sprinkler lines were broken at the connection just above the sprinkler heads. Ceiling tiles fell but lights were restrained by safety wires. In one egress area, two light fixtures swung down when safety wire attachments failed. A 6mw cogeneration plant remained functional. The emergency generators worked, however, power was lost about two hours after the earthquake when the day tank ran out of fuel due to incorrect fuel transfer pump wiring logic.

Several elevator counterweights bent their rails and pulled away, severely limiting the vertical transport of patients. For this facility, ambulatory patients were evacuated by RTD busses. A bulk oxygen tank sheared its anchorage and nearly toppled, being caught by a nearby fence. The UPS for the hospital computer system functioned for awhile after the earthquake, but then the voltage and frequency of the output became erratic and the system failed. In the rooftop HVAC penthouses (a 2.3g peak acceleration was recorded on the roof), rod hung pump fittings were damaged, fan support anchors failed, and vibration isolation mounts with seismic restraints failed.

Holy Cross Medical Center

Radio communications were unavailable after the earthquake due to failure of a roof mounted antenna. Elevators were not functioning and patients were evacuated down hospital stairwells. The bulk oxygen tank overturned. Both potable and non-potable water supply had to be turned off due to leaks. All emergency generators functioned properly. Within the HVAC penthouse, fans were dislodged from mountings and a chilled water line broke, flooding the floors below. Sprinkler lines throughout the facility had numerous leaks at joints above the discharge heads. A HVAC duct which crossed a building seismic joint without an expansion joint was torn apart. Rooms adjacent to the building seismic joints had more damage than other rooms, presumably due to structural impacts. The buried incoming fire water line had failure at the slip joints.

Granada Hills Community Hospital

A water tank on the roof failed and flooded the upper floors of this facility causing severe water damage. The third and second floors were evacuated to the first floor. Emergency power was available and functional and the hospital provided limited patient care and services. The emergency room remained open and two Disaster Medical Assistance Teams were sent to the hospital due to the large number of persons seeking emergency care. Triage was conducted in the parking lot.

Northridge Hospital Medical Center

This facility had considerable water damage due to fire sprinkler and domestic water leaks. One emergency generator failed to start although two others functioned normally. A formaldehyde spill occurred in an emergency room and the neonatal unit was evacuated due to ceiling and lighting damage. The facility turned off gas and water (potable and non-potable) services due to leaks. Having only steam sterilizers available, the hospital was unable to provide full emergency room services. This hospital facility had conducted a nonstructural damage mitigation program prior to the earthquake, which is credited with a rapid return to functional status upon completion of water and HVAC system repairs after approximately two days.

5.6 Glass

Observations of window/wall glass performance in the Northridge earthquake can be divided into two classes: low-rise and high-rise building systems. In the case of low-rise buildings (i.e., one - two story structures), the observations made are consistent with those of past moderate to strong earthquakes. Substantial glass breakage occurred throughout the region affected by the earthquake. This breakage is due to the fact that window framing systems in low-rise construction (especially one story) are not designed to isolate the glass from large building distortions. In fact, window glass is often rigidly mounted within a framework that allows for very little building movement before framing materials come into contact with the glass. As the glass is very brittle within the plane of the window, it shatters the moment it comes into contact with the structure.

On the other hand, high-rise window systems (few to many tens of stories) tend to be more sophisticated from an engineering standpoint as the glass is an expensive and critical element of building function. The window glass and supporting framework is designed to withstand high wind forces, thermal movements of the building and window system, and building sway due to wind and earthquake forces. This is why, for the vast majority of structures severely shaken by this event, very little glass was lost. One of the most serious cases of high-rise glass breakage was in twin eight-story buildings very close to the epicenter. The amount of glass breakage represented less than 5% of the panes, and even this amount was unusual relative to past major earthquakes worldwide.

One of the most significant losses to glass wall systems was related to the gasket material used to cushion window systems in high-rises. It was a common sight on streets bordered by high-rises to see hundreds of pieces of window gasket material hanging loose from their frameworks. This occurred as the building swayed and window glass rocked in the framework, squeezing the gasket material from between the window and the frame. Though not a "failure" like glass breakage, it is a costly endeavor to check the facade thoroughly and reinstall or replace the gasket materials in a manner that will assure water tightness throughout.

5.7 Roof and Ground Mounted Equipment

With some noteworthy exceptions, the performance of roof and ground mounted equipment systems was as expected in an earthquake of this magnitude. Generally, equipment that was adequately bolted down (i.e., anchored reasonably close to code requirements) performed well and equipment that was not bolted down often slid or toppled causing minor to extensive damage. These same observations have been made repeatedly in past earthquakes, thus, there is every reason to believe that if equipment is bolted down, it will perform well.

The significant exception to the above "rule" regarding equipment anchorage relates primarily to heavy equipment anchored at the upper floors or on roofs of low- to mid-rise buildings. In the 1989 Loma Prieta and 1987 Whittier Narrows earthquakes, and particularly the Northridge earthquake, large building support equipment such as chillers, pumps and cooling towers occasionally broke loose from existing anchorage, or pounded seismic "snubbers" until they failed. These failures occurred due to large accelerations in the 1.0 to over 2.0g range and weaknesses in the anchorage, such as marginal size, shallow embedments or lack of edge distance. The upper levels of high-rise buildings do not experience the same "whipping" effect from very high accelerations as the high period of these buildings tends to isolate them from the peak ground motions.

It may be premature to conclude that building code requirements should be upgraded to prevent this type of equipment failure; however, it is reasonable to advocate additional studies of these failures to better understand their causes.

5.8 Contents

One of the most significant causes of damage during the earthquake was the widespread ejection of cabinet contents and overturning of book shelves, storage cabinets and racks. In one manufacturing plant, specialized carbide tooling stored on shelving was thrown onto the floor resulting in chips in the brittle tooling material and mars in the tooling surfaces (machined with tolerance less than 0.001 in.), rendering them useless.

This damage represented a monetary loss of $750,000. Within the region of strongest ground motion, heavy objects such as laser printers and desktop copy machines were also thrown to the floor. This rigid body motion of objects was due more to the impulsive character of the ground motion than the simple vibratory "walking" of objects off their supporting surfaces.

SECTION 6
EMERGENCY RESPONSE

The Northridge earthquake triggered a response effort at every level of government, among organizations of the private sector and by members of the public. This response involved sophisticated communications, highly skilled personnel and the implementation of detailed plans as well as spontaneous volunteer efforts by untrained citizens, many of whom were disaster victims. Both were essential, contributing to a rapid and largely effective emergency response which minimized casualties and further damage.

The main themes of this section correspond to several basic emergency response activities including inter-governmental coordination, search and rescue, fire suppression, emergency medical services and damage assessment.

6.1 Coordination of Governmental Response

The knowledge that a damaging and perhaps major earthquake had occurred was apparent upon cessation of the shaking and the emergency operations centers of many cities and the Counties of Los Angeles, Ventura and Orange rapidly began to fill. Early television and radio coverage of the event provided eyewitness accounts and visual confirmation that damage to structures and lifelines was substantial. As the extent of damage became known, the City and County of Los Angeles, the City of Hawthorne and the County of Ventura declared local emergencies the day of the earthquake. The Governor responded with a state-level declaration and requested that the President issue a federal disaster proclamation.

President Clinton's January 17 disaster declaration included the counties of Los Angeles, Ventura and Orange and numerous cities within those jurisdictions. Hardest hit were Los Angeles, Santa Monica, Santa Clarita, Simi Valley and Fillmore and several unincorporated areas of Los Angeles County. Despite the magnitude, duration and strong ground motion generated by the earthquake, resources and response capabilities within the region were adequate. The occurrence of the earthquake at 4:31 a.m. contributed to a lower than expected number of casualties, weather conditions did not inhibit fire suppression and there were no incidents such as major hazardous materials releases or dam collapse which claimed or threatened the lives of large numbers of people.

Federal response, in addition to the Presidential Declaration, consisted of several types of assistance. After speaking to Governor Pete Wilson and Los Angeles Mayor Richard Riordan, President Clinton sent several cabinet members to Los Angeles to assess disaster assistance needs. This delegation was headed by White House aide John Emerson and included Housing Secretary Henry Cisneros, Agriculture Secretary Mike Espy and Federal Emergency

Management Agency (FEMA) Director James Lee Witt. In addition, federal authorities mobilized four disaster medical units, several mobile communications systems capable of satellite and microwave telephone hookups and twelve urban search and rescue teams. The Army Corps of Engineers initiated the inspection of dams and assigned a total of 280 engineers to serve with their state and local counterparts on damage inspection teams. Officials of the Department of Housing and Urban Development began an assessment of long-term shelter needs and the Department of Transportation joined state and local agencies to inspect highways.

The State of California's Office of Emergency Services (OES) activated emergency operations centers in Sacramento and the southern region at the Los Alamitos Armed Forces Reserve Center. While other state agencies with emergency response functions (e.g. California Highway Patrol, California Department of Transportation, Department of Health Services, etc.) also activated emergency operations centers (EOCs), these agencies coordinate their activities with OES, which serves as lead agency, through representatives sent to the State Operations Center at OES headquarters.

OES regional staff initiated contacts with local operational areas and began collection and evaluation of disaster information as it became available. Liaison personnel were dispatched from the OES Region to operational area EOC's in Los Angeles, Orange and Ventura Counties to relay requests for resources and mutual aid. In addition, a liaison officer reported to the California Institute of Technology to collect and report scientific information on the earthquake to the OES executive staff. Early activities included assisting local jurisdictions in preparing and forwarding declarations of disaster, mobilizing the volunteer engineers who assist local jurisdictions with damage inspection and activating the California-based Urban Search and Rescue Task Forces.

As in any disaster in the United States, the responsibility for basic emergency response in the Northridge earthquake fell to local government agencies. These response activities included suppressing hundreds of structure fires, providing traffic control and security in heavily damaged areas, rescuing those trapped in collapsed structures, restoring public utilities and providing emergency shelter and medical assistance. While local personnel and resources were sufficient for most response activities, cities and counties sought and received assistance under the California Mutual Aid Agreement in the areas of firefighting, law enforcement, damage assessment, search and rescue and emergency medical assistance. Detailed discussion of several areas of coordinated response are included in subsequent parts of this section.

6.2 Search and Rescue

The principal site for rescues in the earthquake was the 120 unit Northridge Meadows apartment complex located near the epicenter where a three story building partially collapsed, killing 16 and trapping 30 others. Structurally, the apartment buildings are of woodframe construction with the ground floors configured as carports and apartments. It was the first floor of the building at 9565 Reseda Boulevard that was crushed in the collapse and reduced to a crawl space of two to three feet. Those who were killed or trapped were buried under the collapsed walls and ceiling.

Approximately 180 residents of the complex evacuated prior to the arrival of firefighters and rescue teams and an unknown number of those trapped in the collapsed structure were assisted to safety by other residents. The search and rescue operation at the apartment complex ultimately involved seven Los Angeles City Fire Department companies and four Urban Search and Rescue (US&R) Task Forces. The US&R teams are part of a state response system as well as a national program sponsored by FEMA. There are 25 US&R Task Forces nationally with eight of them in California (Figure 6-1). The California Task Forces are managed and deployed by the Governor's Office of Emergency Services and all were activated for this earthquake. Four Task Forces were assigned to rescue sites in Northridge at the request of the Los Angeles City Fire Department, and four were staged at the Los Alamitos Armed Forces Reserve Center for quick deployment into the affected areas.

Thirty residents were rescued from the collapsed structure. Eight of the more difficult rescues involved injured persons who, after being extricated by fire and US&R teams, were transported to area hospitals in conditions ranging from serious to critical. Specially trained dogs from the Los Angeles Police Department were brought in to assist in the search for additional victims, however, no additional survivors were found in the apartment building.

The most difficult and time consuming rescue took place in the Northridge Fashion Center where a three-story parking structure had collapsed trapping a worker who was operating a sweeper truck on the structure's first floor. Los Angeles City firefighters, a gas company crew and the Orange County US&R Task Force used hydraulic jacks, sledge hammers and saws to reach the man who was pinned and in critical condition. An aqueous foam was injected into the rescue site to prevent the ignition of leaking fuel from the truck. After nearly seven hours, the man was removed from the rubble and transported by helicopter to the UCLA Medical Center where he was stabilized and will recover.

While rescues were made at various other sites, those made at the Northridge Meadows and the Northridge Fashion Center involved the greatest number of victims as well as the most complex incidents.

Rescue efforts benefited by the timing of the event, occurring when the Los Angeles Fire Department's off-going shift could be held over to provide double staffing for fire suppression and search and rescue. OES mobilization of the US&R Task Forces greatly enhanced the department's search and rescue capabilities and, in addition, freed firefighters to suppress the several hundred structure fires reported the first day.

FIGURE 6-1 One of Eight California-based US&R Teams Activated for the Northridge Earthquake

6.3 Fire Suppression

Like search and rescue, the focus of fire suppression was the San Fernando Valley area of the City of Los Angeles. Immediately following the earthquake, the Los Angeles Fire Department activated it's emergency response plan, assumed the Earthquake Emergency Operational Mode and requested mutual aid. Power outages and the failure of two back-up generators resulted in the loss of the department's computer dispatch system for six hours until the power was restored. During the outage, the department relied on "manual mode" dispatching and reported that communications were not interrupted nor impaired in any way by the computer system failure.

By 6:45 a.m., approximately 50 structure fires had been reported in addition to numerous ruptures in water and natural gas mains. The most significant incidents involved fires at three separate mobile home parks caused by rupture of natural gas valves or mains claiming 120 mobile homes. Firefighters arriving at the scenes of these incidents encountered fire hydrants with little or no pressure requiring relay operations and water shuttles to combat the fires. All residents of mobile homes were evacuated and no serious injuries were reported.

The earthquake caused ruptures of both water and gas mains at the intersection of Balboa Boulevard and Rinaldi Street. A small pickup truck which had stalled due to flooding from the broken water main ignited the leaking gas as the driver attempted to restart his engine. This incident resulted in a bizarre scene in which flames from the ruptured gas main shot high into the air as water cascaded down the street. The fire spread to nearby homes and five single-family structures were completely burned. The residents were evacuated by firefighters and the only serious injury was to the driver of the truck which ignited the fire.

In Pacomia, a 10 inch (250mm) oil pipeline ruptured spilling thousands of gallons of crude oil onto Wolfskill Street, east of Laurel Canyon Boulevard. The oil ignited sending walls of flame down the street. Before the blaze could be controlled, two houses and seventeen cars were destroyed.

The Los Angeles Fire Department reported that by 9:45 a.m. on January 17, all fires in the San Fernando Valley were under control and that there were no further major earthquake-related structure fires in progress. On the following day, twenty-nine tanker trucks containing 78,000 gallons of water were deployed throughout the valley to supply fire companies for possible outbreaks. During the first 24 hours after the earthquake struck, there were between 400 and 500 reported structure fires, about four times the normal number.

6.4 Emergency Medical Services

Over 30 hospitals, mainly located in the San Fernando Valley, sustained some degree of damage and four medical centers, including the Veterans Administration (Sepulveda), Olive View and

Holy Cross in the San Fernando Valley and St. Johns in Santa Monica, required complete evacuations of patients and staff. Two of the facilities, the Olive View Medical Center and the Sepulveda Veterans Administration Hospital, had been rebuilt following the 1971 San Fernando earthquake. For those hospitals severely impacted, noncritical patients were discharged and those with more serious medical conditions were transferred to other facilities. Until mobile medical units arrived, some operations and treatment were conducted outdoors.

Upon the occurrence of the earthquake, emergency medical services authorities in Los Angeles, Ventura and Orange Counties were activated, reported to their respective emergency operations centers and began a survey of medical facilities, their capabilities to treat patients and their need for resources. As reports became available, it was apparent that most evacuations and service disruptions were due to nonstructural damage and utility outages. The only significant structural damage was to St. Johns Hospital in Santa Monica which was completely evacuated and closed. All impacted hospitals were in Los Angeles County; surrounding counties including Ventura, Orange and Santa Barbara reported minor or no damage, although some experienced power failures and relied on emergency generators for the first several hours after the earthquake.

The Emergency Medical Services Authority (EMSA), the state agency responsible for the coordination of medical mutual aid, placed Disaster Medical Assistance Teams (DMATs) on alert and requested ten Air Ambulance Helicopters from the 175th Medical Brigade. Eight DMATs were mobilized and the air ambulances were deployed to Los Alamitos to stand by for missions. On January 18, at the request of Los Angeles County Emergency Medical Services, the first Disaster Medical Assistance Teams were assigned to Northridge Hospital and Granada Hills Hospital. Additional DMATs from other states were activated and deployed to clinics in Santa Monica, Valencia and Canoga Park.

As the numbers of displaced persons from the earthquake swelled to over 20,000, spread out in forty-two shelters and fifty public parks, the need for public health outreach prompted emergency medical authorities to dispatch mobile medical vans. In addition, nurses were deployed to the Red Cross shelters and disaster application centers to provide basic medical care and advice. By January 26, the emergency medical response began scaling back and by February 2, all DMATs had been deactivated and withdrawn and EMSA emergency operations centers had shut down. The final report of casualties compiled by EMSA included a total of 8,649 injuries, 1,567 hospital admissions and 57 deaths in Los Angeles and Ventura Counties. The number of deaths directly attributable to the earthquake, according to the Los Angeles County Emergency Medical Services Authority, is placed at 32 (see Section 7.1).

6.5 Damage Assessment

The Northridge earthquake caused severe and widespread damage to residential and commercial buildings, lifelines and utilities in the Los Angeles area. Hardest hit were the San Fernando

Valley communities of Northridge, Reseda and Granada Hills which are part of the City of Los Angeles, the Cities of San Fernando, Fillmore, Santa Clarita, Santa Monica and the Ventura County City of Simi Valley.

Post-earthquake damage assessment is a local government responsibility, but in an event such as the Northridge earthquake, local efforts are supplemented through mutual aid by the volunteer engineers program sponsored and managed by the California Governor's Office of Emergency Services (Figure 6-2). This program proved to be critical as the impact of the January 17 earthquake overwhelmed the resources of individual jurisdictions. In the largest mobilization in the program's 18 year history, approximately 530 inspectors were drawn from five professional organizations including the California Building Officials, the Structural Engineers Association of California, the American Society of Civil Engineers, the American Institute of Architects (California Council) and the American Construction Inspectors Association. An additional 280 inspectors from the Army Corps of Engineers were activated through the state's Master Mutual Aid Agreement.

The City of Los Angeles boasts the world's largest building department but its 500 inspectors proved to be only about half the number of inspectors needed to inspect over 50,000 buildings between January 17 and February 2. An additional 500 inspectors from the Office of Emergency Services and the U.S. Army Corps of Engineers were requested through the mutual aid system and provided assistance. The inspections conducted are sometimes referred to as "sweeps" in that the assessments performed are rapid and intended to determine the safety of structures; they are not thorough evaluations (Figure 6-3).

As of February 2, the Los Angeles Department of Building and Safety, assisted by volunteers, had inspected 54,384 structures, 80.8% of which were residential buildings, 10.8% were classified as non-specific or mixed use and 8.4% were commercial. Of this number, inspectors declared 1,946 structures (76.7% residential, 21.5% commercial and 1.8% mixed use and non-specific) to be unsafe and posted them with red tags forbidding reentry. An additional 7,442 structures were "yellow tagged" indicating limited entry. A total of 31,256 structures, approximately 57.5%, were declared safe for reentry without restriction. The total estimated loss to all structures in the City of Los Angeles was $1.85 billion. The results of safety inspections in other impacted cities is contained in Table 6-I.

Because of the importance of the damage assessment process to public safety and its high visibility to the media and public, there are frequently issues which arise over the pace of inspections and the decisions made regarding access to property in the impacted areas. The progress of safety inspections did not emerge as a major public issue but officials with the City of Los Angeles Department of Building and Safety acknowledged that their system for inputting the tremendous volume of assessment data requires modification. This data is currently entered into the department's computer system by hand which is time consuming and expensive. The department is considering use of a scantron for data reduction or hand held computers by inspectors.

Approximately two weeks after the earthquake, reports appeared in the news media indicating that as many as 20% of the buildings "red tagged" by inspectors were not sufficiently damaged to prohibit reentry and should be reinspected (Figure 6-4). The City's Department of Building and Safety responded by ordering reinspections of some structures and reiterating that the sweeps were preliminary and that most building owners should seek a thorough structural evaluation, independent of the structural safety assessment conducted by the department. The safety assessment "sweeps" tend to be conservative and, due to the tremendous demand for inspections in this earthquake, make the process vulnerable to charges of classification errors and delays.

Los Angeles city officials reported that some green and yellow tags had been stolen and used to replace red tags by building owners and merchants who feared the loss of tenants. This practice was not believed to have been widespread.

FIGURE 6-2 Volunteer Safety Inspectors Receive Briefing Prior to Assignment

FIGURE 6-3 Inspectors Cordon Off Damaged Residence in Northridge

FIGURE 6-4 "Red-tagged" Residence in San Fernando Valley

TABLE 6-1 Summary of Safety Assessment Inspections and Placards

Totals as of February 16, 1994

JURISDICTION	TOTAL NUMBER OF BUILDINGS INSPECTED	SUMMARY OF POSTED BUILDINGS			REMARKS
		GREEN	YELLOW	RED	
City of Burbank	1,820	UKN	160	21	
City of Bellflower	22	2	0	0	
City of Calabassas	85	47	24	14	
City of Culver City	638	484	124	30	
City of Glendale	1,025	988	9	30	
City of La Mirada	10	10	0	0	
City of Los Angeles	54,384	31,256	7,442	1,946	22,355 dwelling units vacated 45,415 buildings damaged
City of Pasadena	320			4	Post Unsafe Buildings only
City of Santa Clarita	5,538	5,169	253	116	2,651 of green tagged structures have damage
City of Santa Monica	2,717	2,301	293	123	Initial repair and stabilization reducing number of red and yellow placards
City of West Hollywood	9	3	UNK	UNK	
City of Westlake Village	11	0	1	0	
County of Los Angeles - Unincorporated Areas					
Firestone	9	6	1	2	
La Puente	10	10	0	0	
Bellflower	1	1	0	0	
San Gabriel	3	3	0	0	
East Los Angeles	120	84	19	17	
Santa Clarita	775	674	66	15	
County of Ventura					
City of Camarillo	UKN		1		Sewage Treatment Plant
City of Fillmore	2,049	1,532	221	81	
City of Moorpark	UKN		48	3	
City of Simi Valley	UKN		396	68	
City of Thousand Oaks	UKN		101	1	
County of Ventura - Unincorporated Areas					
Piru	UKN		26	9	
Unincorporated	UKN		14	5	
Mobile Homes					
Los Angeles County	UKN	188	154	36	
City of Fillmore	UKN		98	117	
City of Simi Valley	UKN			622	
TOTAL	**66,546**	**42,752** **77%**	**9,441** **17%**	**3,060** **6%**	

SECTION 7
SOCIETAL IMPACTS

The Northridge earthquake illustrates the immense potential for damage and social disruption that earthquakes present. It also provides a natural laboratory in which social scientists can obtain important information on the social impacts earthquakes produce. This section presents general information on selected earthquake impacts; discusses activities that were undertaken by public- and private-sector organizations to cope with the disruption the earthquake caused; and examines initial plans and programs adopted by the City of Los Angeles to facilitate recovery.

7.1 Deaths and Injuries

Although 57 persons are reported to have died as a result of the earthquake, that number is inflated, because a number of heart attacks were attributed to the event that were likely not earthquake-related. The largest single contributor to the death toll in the earthquake was the partial building collapse at the Northridge Meadows apartment complex; sixteen persons were killed when the top two stories of the apartment building collapsed onto the ground floor. All the fatalities at that location were residents of first-floor apartments. The causes of other fatalities include fire, falls (including a fall from a sixth-story window), a motorcycle accident at the site of a freeway collapse, electrocution, and injuries sustained when the victims were struck by flying objects in their homes.

It is unclear at this time how many people were injured in the earthquake. Ten days after the event, the number of hospital-treated injuries was reported to be 7,000. However, many early injury reports were based only on statistics from hospital emergency departments – statistics that also included individuals who sought treatment after the earthquake for medical complaints that were not earthquake-related. A careful analysis of emergency department records will be needed to determine what proportion of hospital visits in the impact area actually involved injuries or medical complaints. An analysis that was done in approximately 50 hospitals in the area of impact following the Loma Prieta earthquake indicated that only about 45% of the cases seen in emergency departments in the first twelve hours after the earthquake were actually attributable to the event.

On the one hand, general statistics collected from hospitals tend to overestimate the number of persons who sought hospital treatment for earthquake-related problems. On the other hand, looking only at hospitals and the problems they treated will likely underestimate the health impacts of the earthquake. To get a clear idea of the nature and extent of earthquake-related injuries and medical complaints, it will be necessary to take into account other settings in which people sought and received treatment. These settings include (but are not limited to) community clinics, urgent care centers, and Red Cross and Salvation Army shelters.

Studies of other recent earthquakes suggest that health risks can continue for a period after the event; injuries can result from clean-up and repair efforts, for example. Two of the deaths attributed to the Northridge earthquake occurred after the event, when a helicopter inspecting a pipeline crashed. When the weather began to turn rainy and cooler after the earthquake, officials expressed considerable concern that persons sheltering outdoors (especially children) would begin developing respiratory problems and other illnesses.

The time of day the earthquake occurred was a very important factor in the relatively low incidence of deaths and injuries. This is particularly true in light of the severe freeway damage that the earthquake caused and the number of normally high-occupancy structures throughout the region that collapsed or had major damage. If the Northridge earthquake had occurred a few hours later, or worse, on a day that was not a federal holiday, the death toll would doubtless have been higher by several orders of magnitude, and injuries would have increased proportionately.

7.2 Housing

The earthquake created a large need for emergency shelter. People were forced from their homes not only because of earthquake damage but also because of the loss of utilities, particularly water. Additionally, as has been seen in other recent U. S. earthquakes, large numbers of people sought shelter outdoors because of fear of being inside buildings, particularly since aftershocks were occurring regularly. Some of these displaced residents pitched tents in their yards or stayed in camping vehicles near their homes. Many others chose to stay in public parks and other open spaces. At its peak during the week following the earthquake, the population that sought shelter in parks numbered approximately 20,000. Soon after the earthquake, organized efforts began to persuade this population to move to officially designated shelters, where more services were available, as well as to provide tents and outdoor, tented "refuge centers" for those who remained unwilling to stay indoors.

The Red Cross began opening shelters immediately after the earthquake struck. At the peak of the emergency, the Red Cross operated 41 shelters, and the Salvation Army operated four. As of January 27, ten days after the earthquake, 36 Red Cross shelters and four "refuge centers" or "tent cities" were still operating, providing shelter to an estimated 8,700 persons. By February 4, 27 shelters remained open, 3,453 persons remained in shelters, and all the "refuge centers" had been closed.

It is difficult to determine at this time how extensive the need will be for long-term housing. As of February 16, the Department of Building and Safety in the City of Los Angeles had inspected about 54,384 structures of which 1,946 had been red-tagged (refer to Table 6-I). A total of

22,355 dwelling units had been vacated. Residents of less damaged units will also be forced to seek other housing while repairs are being made. Damage to housing units was widespread outside Los Angeles, particularly in Santa Monica, Santa Clarita, Fillmore, and Simi Valley.

A survey conducted by the *Los Angeles Times*, which was published on January 26, suggests that residential damage was quite widespread in the county. About 10% of the respondents contacted countywide indicated that their homes had received significant damage in the earthquake. The same proportion – one respondent in ten – reported losses to their homes of $5,000 or more. Damage appeared to disproportionately affect Latino residents and households with very low incomes; 4% of Latinos and 6% of the very low-income group surveyed reported that their homes were unlivable because of the earthquake.

7.3 Businesses and Economic Activity

As is the case with housing, it is not possible at this time to get a clear idea of how many businesses in the area of impact were damaged by the earthquake, or what kinds of damage and disruption they experienced. It is clear, however, that the earthquake had a significant and widespread impact on business activity. Both structural and nonstructural damage were major sources of business disruption. Businesses were also forced to close because of utility damage and loss of utility services and because of concerns about whether or not damaged buildings were safe to occupy. In Los Angeles County, commercial areas in the San Fernando Valley near the epicenter and in Santa Monica were particularly hard-hit.

Businesses typically experience a range of problems in attempting to recover from earthquakes. Very few small businesses have earthquake insurance. Many business owners can find themselves in financial difficulty if they are forced to shut down for more than a short period. Businesses that are forced to relocate because of earthquake damage may end up in less desirable and profitable locations. Owners whose buildings were destroyed or severely damaged must face various problems related to the reconstruction process, such as compliance with seismic and other codes, and they must also seek financing for repair and reconstruction. While grants of various kinds are often made available to households that have earthquake losses, loans are by far the most common form of post-disaster recovery assistance for businesses. For the business owner, obtaining a loan to cover disaster losses typically means taking on additional debt.

When business owners have had a chance to assess their losses and decide how to go about recovering from the earthquake, they are likely to turn to a range of sources to obtain funding for recovery, including savings, family members, bank loans, and government loans. The Small Business Administration (SBA) Disaster Loan Program, which also makes disaster loans available to homeowners, is the largest source of government loans for businesses that suffer disaster losses. The SBA loans money to cover both direct physical losses, such as damage to buildings, inventory, and equipment, and "economic injury," defined as losses that occur for reasons other than direct damage, such as business interruption or loss of customers. Table 7-I presents data on the processing of SBA loan applications, as of March 6. As the table indicates, although a large number of business loan applications had been distributed at Disaster Application Centers and other locations, just 17,000 applications had been received by that date. Only about 4% of the business loan applications had been approved, but the amount approved for loans was already over $27 million. About 5,200 business owners had filed applications for economic injury loans, and approximately 100 of those applications, totaling about $3.5 million, had been approved.

TABLE 7-1 Status of SBA Business Loan Applications
(as of March 6, 1994)

Loan Type	Issued	Received	Approved	Pending	Amount Approved
Business	78,170	11,788	520	9,976	$27,164,000
Economic Injury	25,122	5,211	107	4,760	$ 3,502,200

Following the earthquake there was considerable concern that transportation system damage could further disrupt the Southern California economy, which was already seriously affected by the recent recession. Further study will be needed to determine whether freeway closures and the development of alternative transportation routes affected productivity and business revenues.

7.4 Damage to Hospitals and Schools

Emergency-care resources were more than sufficient to handle the injuries and other medical complaints the earthquake produced. Since relatively few people were injured, and since the health-care system in Greater Los Angeles has considerable capacity, the system was able to respond. However, many hospitals in the affected region did experience damage and disruption that could have resulted in problems had the demand for emergency care been greater. Three damaged hospitals near the epicenter were closed for a period of time following the earthquake. Days after the earthquake, St. John's Hospital in Santa Monica had to be evacuated because of structural damage, and severe damage was later found at one of the hospital facilities at Los Angeles County/USC Medical Center. According to a story that appeared in the *Los Angeles Times*, countywide there were eighteen hospitals that experienced problems serious enough to force the closing of wings or floors, and 719 patients had to be transferred as a result of hospital damage and disruption. In addition to scattered structural damage (see Section 3.2), nonstructural damage and utility-related problems appear to have been major sources of the problems hospitals experienced (see Section 5).

The Los Angeles Unified School District, with approximately 750 elementary, middle, and secondary schools, is the nation's second-largest public school system. A number of school buildings experienced severe damage; most of the seriously damaged and disrupted schools were located in the San Fernando Valley near the epicenter. Schools throughout the affected region were closed for eight days following the earthquake. Approximately 75 schools were too badly damaged to open on Tuesday, January 24, when the other schools reopened. As of January 29, 33 schools were still closed. Of this number, the most hard-hit were two high schools, four middle schools, and two elementary schools, all near the epicenter. California State University at Northridge, which was forced to close, reportedly sustained several millions of dollars worth of fire, structural, and nonstructural damage.

When the schools began to reopen, school officials faced several major issues, including how to provide appropriate counseling and reassurance to students who had just gone through a very frightening experience; how to provide water to students in educational facilities that were still without water service, and what to do in areas that were under "boil orders;" how to arrange for schooling for those children whose schools had been severely damaged; how best to serve children who were living in shelters; and how to arrange daily schedules and educational activities in schools that were also being used as shelters for earthquake victims.

7.5 Reducing Earthquake Impacts: Priorities in the Post-Impact and Early Recovery Periods

Restoring Utilities

Electrical power: The Northridge earthquake created the first total blackout in history for the Los Angeles Department of Water and Power's (LADWP) approximately 1.3 million customers. In the northern part of Los Angeles County, an additional 750,000 Southern California Edison customers lost power as did 535,000 of their customers in Ventura and Santa Barbara counties. For LADWP, this event was a test of the changes they had made in their equipment and emergency response procedures that were developed after the 1971 San Fernando earthquake.

Within 15-30 minutes after the earthquake, parts of LADWP's system began coming back on line; and by late Monday afternoon, 40% of the system had been restored. By Friday, four days after the earthquake, the total system was operating and able to supply all customers with power.

To begin restoration of the system, LADWP assessment teams were sent out to conduct visual inspections of the system as well as using information coming into LADWP's Emergency Energy Center. Two activities were given priority in the early phases of the response period: restoring transmission lines coming into the city from the north which were down because the foundations under two towers failed; and repairing receiving stations in the north San Fernando Valley. When these two priority tasks were completed, the distribution system would then be able to restore power throughout the area.

It appears that much of the mitigation they had undertaken following the San Fernando earthquake was successful. LADWP expended resources following that event to assess what went wrong, why, and what could be done to remedy those problems. Unlike the 1971 event, the Northridge earthquake caused no damage to major transformers and no major switches went down.

Water Systems: The earthquake caused serious damage to major water transmission and distribution lines. LADWP lost its aqueduct from the north into the San Fernando Valley. The Metropolitan Water District (MWD) lost its two aqueducts from the north, but its aqueduct bringing water into the metropolitan area from the east was undamaged. The existence of this aqueduct allowed water to be retained in the southern parts of the city, leaving the San Fernando Valley and the Santa Monica Mountains areas without potable water. The LADWP was able to draw water from its reservoirs (that had a 5-10 day water supply) until the first of the northern aqueducts was repaired. The MWD's aqueduct was the first to return to operation on Thursday night, returning water to the heavily damaged valley areas. By January 24, both of LADWP's aqueducts were back in service.

Although the water transmission system was restored relatively quickly, impacts were still being felt through the second week after the earthquake. LADWP was having a major problem repairing breaks to the distribution system in the San Fernando Valley – which had been "shattered" – and to the Granada Trunk Line that ran along the lower elevation of the Santa Susana Mountains. Without this trunk line, water could not be restored to the residential areas higher up in the mountains. To overcome this problem, LADWP borrowed 24 pumpers from the City's Fire Department and had them stationed along the Susana Trunk Line that ran parallel to the Granada, but higher up on the slopes. By pumping water into the system at this level, water flowed down through the system, allowing as many as 30,000 more homes to have their water restored.

"Boil water" advisories were issued for a large part of the valley immediately after the earthquake. These advisories continued, for ever smaller sections of the city, throughout the next two weeks. The advisory was still in effect on January 28 for a small area of the Santa Monica Mountains.

The distribution of water to areas and households that needed it became an extremely important activity very soon after the earthquake struck. Because potable water was unavailable for hundreds of thousands of people early in the post-disaster period, LADWP was faced with major problems of water provision. As one stop-gap measure, LADWP contracted with truck companies to station water tankers at shelters (both official and unofficial). In conjunction with the Office of Emergency Services (OES), LADWP also arranged to have bottled water delivered to shelters, Disaster Application Centers (DACs), and schools that needed water in order to re-open.

Large quantities of both bulk and bottled water that were provided by private vendors were also used in this effort.

Sheltering and Rehousing Victims

Beginning a very short time after the earthquake, a major multi-organizational and inter-jurisdictional effort developed around the provision of services to persons who were out of their homes due to the earthquake. Several large tasks had to be addressed. First, it was necessary to provide food, water, sanitation services, and other services to address basic needs, as well as to provide information on available disaster services to people who had been displaced as a result of the earthquake. As noted earlier, the Red Cross and Salvation Army provided many of these services in their shelter facilities. Water was brought to central locations and distributed to people who were affected by the damage to the water distribution system. When it became apparent that many earthquake victims felt more secure sheltering outdoors, an organized effort developed to deliver tents to sites where people were congregating and to add tents as a supplemental form of shelter at the Red Cross facilities, which were usually located at schools. The State Office of Emergency Services and other agencies began outreach efforts, canvassing neighborhoods and places where people were using improvised shelter arrangements and providing information on the range of shelter options and other disaster services that were available.

Second, it was necessary to provide displaced residents with the kinds of information they needed to begin returning to their homes or making alternative shelter and housing arrangements. In many cases, this involved convincing fearful residents that their homes had been inspected and that they were indeed safe to occupy. In the City of Los Angeles, for example, the City's Department of Personnel took the lead in organizing "reassurance teams;" typical teams were composed of building inspectors, Red Cross workers, Housing Department representatives, translators (where needed), members of the clergy, and mental health workers. These teams provided information to displaced persons on the status of their buildings; reassured them that they could go back into their homes, in cases where those homes were found to be safe; and provided various forms of assistance to persons who were permanently displaced or who still would not go home. Tents, cots, and other supplies were provided to those persons who preferred to remain outdoors.

Three days after the earthquake occurred, an informal task force was established to begin dealing with earthquake-generated housing problems. Participating in the task force were representatives from Los Angeles City and County, the Red Cross, the Office of Emergency Services, several other state agencies with housing responsibilities, and representatives of FEMA and the Department of Housing and Urban Development (HUD). Three categories of issues were identified: immediate sheltering; the opening of disaster application centers (DACs) and the housing programs that would be available in the DACs; and longer-term recovery issues. Two main objectives were outlined by the task force at that time: getting people into shelters and registered at the DACs for various forms of disaster assistance; and getting people from the shelters and other informal shelter sites into housing.

Recognizing that many of those displaced by the earthquake were likely to be low-income families, HUD initially made approximately 10,000 vouchers available to subsidize rents for persons who were left homeless by the earthquake and who had to find alternative housing. This number was later expanded, and as of February 8, approximately 14,000 certificates had been issued and 915 new housing contracts approved.

At the time of this writing, the shelter population had declined to about 3,000, indicating that displaced residents were either returning to their homes or making alternative living arrangements. As of February 8, FEMA had received approximately 215,000 applications for some form of housing assistance – e.g., for home repairs or housing allowances – and approximately 11,600 loan applications had been filed with the Small Business Administration Disaster Loan Program for home reconstruction or repair.

Restoring Transportation System Capacity

Dealing with transportation system damage and disruption became a very important priority, because it was recognized that damage to highways, bridges, and overpasses had the potential for producing negative economic impacts and slowing recovery. The severe damage at the intersection of Interstate 5 and State Route 14 meant a potential commuting nightmare for hundreds of thousands of residents of the Antelope Valley and neighboring areas. Travel on the Santa Monica Freeway, the busiest highway in the U. S., was seriously disrupted due to the failure of two bridge spans (see Section 3.1).

As was the case after the 1989 Loma Prieta earthquake, a large multi-organizational network emerged after the Northridge event that focused on the design and implementation of an alternative transportation system to compensate for the loss of capacity on key transportation links. Various transportation agencies, including Caltrans, the City of Los Angeles's Department of Transportation, and the Metrolink rail service were involved in devising a comprehensive strategy for overcoming earthquake disruption. As part of this strategy, temporary roads were constructed and traffic was rerouted onto surface streets to circumvent freeway closures. High-occupancy-vehicle lanes were designated on streets and roadways to encourage car-pooling. New train cars were added to the Metrolink system, train service was expanded, and new stations were built. Employers were asked to encourage their workers to take advantage of flex-time and telecommuting arrangements. A massive campaign was undertaken to inform the public about new transportation options and encourage their use.

Unlike residents of the Bay Area, who had long experience with subways, trains, and the ferries they had to rely on when the Bay Bridge was closed, residents of Greater Los Angeles have little experience with mass transit, and they prefer their automobiles. Area residents have been told that it will probably take a year before the damaged transportation links are restored. Although they appear to be adjusting well, it is not yet clear how long the changes in travel patterns will persist and what broader social and economic consequences they will have.

Provision of Disaster Assistance

The Presidential disaster declaration was made on the day of the earthquake, which meant that disaster assistance would rapidly be made available to earthquake victims and affected jurisdictions. DACs began operating three days after the earthquake, on January 20 – a rapid response on the part of the federal government. (In contrast, it had taken eleven days for centers to open following Hurricane Hugo in 1989). Twelve DACs were opened initially, two more opened within a week of the earthquake, and plans were made to make mobile DAC services available to make it easier for people to apply for assistance. Present in the DACs were representatives of federal, state, and private-sector agencies (such as the Red Cross) that make various forms of assistance available to disaster victims. A partial list of the services available at the DACs include FEMA's housing assistance and individual and family grant programs; the SBA's loan programs for homeowners and businesses; disaster unemployment insurance; assistance from the Internal Revenue Service for persons who may have lost tax records; Red Cross financial assistance for households that experienced losses; and state programs such as the California Natural Disaster Assistance Program (CALDAP). Other forms of disaster assistance, such as food stamps and housing vouchers, were distributed at other locations.

In addition to applying in person, it was also possible for earthquake victims to apply for assistance by telephone. As of February 8, nearly 307,000 persons had applied for some form of disaster assistance, either at the DACs or through teleregistration.

Early Recovery Planning

It is commonly taken for granted that the best time to pass earthquake hazard reduction legislation is after an earthquake disaster has occurred. The Northridge earthquake was no exception.

On January 26, the Los Angeles City Council established an *ad hoc* Committee on Earthquake Recovery that would consider all earthquake recovery and reconstruction issues and legislation, and would then make recommendations to the full City Council concerning these measures. All earthquake-related items on the City Council's agenda were suspended, pending review by the Committee on Earthquake Recovery, with the exception of one item pertaining to the rebuilding of businesses that was taken up by the City Council on January 28. Procedures were established that would expedite the process whereby earthquake-damaged buildings that housed businesses could be rebuilt as they were at the time of the earthquake, as long as they met all codes that were in effect at the time they were initially constructed. This measure was justified on the grounds that it would allow businesses to be restored as quickly as possible and not hinder economic recovery.

The first meeting of the *ad hoc* Committee was held on January 28. One policy statement and five emergency ordinances were considered by the Committee and sent to Council. The policy statement that was approved stated that all buildings with structural damage resulting from the earthquake or any aftershocks must be brought up to **current** seismic codes.

The four emergency ordinances that were approved and sent on to the full Council for adoption stated that:

- Non-engineered masonry chimneys would no longer be allowed in residential structures.
- All pre-1976 tilt-up buildings would have to be retrofit, including those that had not been damaged in the earthquake.
- Debris removal would be done by the City without charge to the property owner.
- New permitting would be required for repair of damaged masonry walls and for the construction of any new walls.

Currently, no permits are required for masonry walls under six feet (2m) high. This ordinance would require permits for any wall over 3 1/2 feet (1m) high and would require their seismic strengthening.

The City of Los Angeles is widely known for its history of efforts to pass seismic hazard reduction measures, and has enacted and enforced substantially more of these measures than any other city. This early legislative activity, which is certain to be followed by other recovery-related ordinances and initiatives, indicates the commitment of the city to increasingly protect its population from future earthquake disasters. It also demonstrates that its recent experience in other disasters – the civil unrest in 1992 and the fires in late 1993 – and its extensive recovery planning process have sensitized the City to many issues that arise almost immediately following a disaster that could have long-term consequences. But Los Angeles is only one of the many jurisdictions – cities and counties – affected by the Northridge earthquake. Further attention must be given to the measures taken by other Southern California communities in order to better understand the diversity of approaches being taken as the recovery process begins.

SECTION 8
CONCLUSIONS AND RECOMMENDATIONS

While it is too early to assess the full impact and significance of the Northridge earthquake, the authors of this report offer some tentative conclusions based on their fieldwork observations and experience in past earthquakes. The importance of documenting these conclusions, generalizations and lessons learned cannot be underestimated.

Social scientists have observed that the period immediately following a major disaster is characterized by a "teachable moment," a narrow time-window when the full attention of elected officials and key decision-makers is focused on the significance of the event. Like the data many researchers collect after an earthquake like that of January 17, this time-window is perishable and the window must not be permitted to close before the event has been captured and analyzed from the multiple perspectives represented in this report.

This report on the earthquake offers perspectives from the earth science, engineering, and behavioral science communities. The conclusions and recommendations contained in this section are generally those of the contributing authors to the individual sections on the same subject.

8.1 Seismology, Geology and Geotechnical Aspects

The Northridge earthquake was a moderate-sized event yet may prove to be the most costly natural disaster in American history because the fault rupture occurred directly beneath the populated San Fernando Valley. Much larger earthquakes, such as 1992 Landers (M7.3) and 1989 Loma Prieta (M7.0) did less damage because they were centered farther away from urban areas. Fortunate from the standpoint of lifeloss was the fact that this earthquake occurred at 4:31 a.m., when there were very few people on freeways, in parking structures, and in other large buildings that were damaged.

The earthquake occurred on a "blind thrust" fault. These are compressional faults which are difficult to recognize because they do not break the surface of the earth. Although the January 17 earthquake occurred within a recognized system of thrust faults, the specific fault segment that ruptured was an unmapped structure. Other areas within metropolitan Los Angeles where these types of features have been recognized include the Elysian Park Fault System which passes close to downtown Los Angeles and Santa Monica and the Compton-Los Alamitos trend which extends northwestward across the central part of the Los Angeles basin. These structures are capable of producing earthquakes the size of Northridge or larger.

Earthquakes the size of the 1994 Northridge event occur every few decades in the Los Angeles area and probably will continue to occur (1933 Long Beach, 1971 San Fernando, 1994 Northridge) in the future. Society must be prepared for these relatively common and potentially devastating events.

The earthquake produced one of the best sets of strong ground motion records ever recorded. There are a significant number of recordings with accelerations over 1g and velocities over 100cm/sec. These large values may be typical of the ground motions likely to occur in earthquakes of magnitude six or seven.

In addition to the immediate epicentral area of Northridge which was severely impacted, there are pockets of damage in other regions such as Sherman Oaks, West Hollywood, and Santa Monica. Focused studies are needed to identify the site conditions, wave propagation effects, or earthquake source complexities that are responsible for damage in those areas.

The technology is now available to provide real-time earthquake information for emergency response and recovery purposes. This information includes source parameters of location and magnitude, earthquake shaking intensities, and estimates of damage, casualties, displaced individuals and dollar losses. The Caltech-USGS Broadcast of Earthquakes (CUBE), currently the only system providing real-time data on magnitude and location of earthquakes in Southern California, experienced hardware and software problems in the earthquake. Nevertheless, the CUBE system provided information on the earthquake main shock within one hour and aftershocks within minutes. The Northridge earthquake provided an important test of these real-time monitoring and information systems upon which emergency services agencies, utilities and lifelines will increasingly rely for critical decisions affecting response and recovery.

8.2 Structures

Highway Bridges

The following general conclusions can be made from the performance of bridges during the Northridge earthquake.

Bridge retrofit programs are effective. Although many cable restrainers failed, they were generally of a design that has since been superseded by Caltrans. Also, some restrainers that failed catastrophically did so after collapse of nearby columns and loss of support for gravity loads. In these instances, the cable loads far exceeded their design forces because they were then supporting the self-weight of several spans of the bridge. However, some restrainers might have failed due to improper installation. In at least one instance, the nuts on several restrainer cable studs were found to be missing with no evidence of stripped threads. Column jackets appeared to work well and none showed signs of damage or distress despite strong ground shaking nearby.

Prioritization algorithms for bridge retrofit need to be reexamined. At least one bridge that partially collapsed would probably pass the current screening procedures and not be identified as vulnerable. Structure attributes such as skew and the unintended participation of nonstructural elements (e.g., walls and flares) need to be further addressed. Multicolumn bents should also be elevated in the priority ranking procedures.

Other conclusions include:

- Assessment of bridge vulnerabilities should not overlook the vulnerabilities of co-located pipelines.
- Abutments and internal hinge seats must be generously proportioned to accommodate large relative movements in flexible structures.
- The combination of high vertical ground accelerations in bridges with high curvature may significantly decrease column axial loads and adversely affect shear capacities.
- Approach slabs that are tied to abutment back walls can successfully bridge slumped fills behind these walls and provide continued access.

Buildings

The buildings outside the area close to the epicenter of 1994 Northridge earthquake performed as expected. However, in the area close to the epicenter, within a 15 mile (25 km) radius, where most of the severe damage occurred, there were several examples of structures which experienced damage that exceeded expected levels.

The ground motion showed erratic peaks and frequency characteristics which influenced a wide range of buildings, both structurally and nonstructurally. Most of the damaged structures seemed to perform according to expectations given the strength of the ground motion. However, severe, irrepairable damage and life threatening collapses indicated that the severity of damage increases in the absence of a redundant structural system. The timing of the earthquake prevented extensive loss of life in some of the public buildings which collapsed (parking garages, office buildings and commercial centers).

This earthquake uncovered the weakness of "non-engineered" or "pre-engineered" wood structures which need much more attention and supervision during design and construction than is currently practiced. At the same time, this earthquake indicated that well-known vulnerable structures such as unreinforced masonry, nonductile concrete and tilt-up structures should be retrofit and rehabilitated as soon as possible.

Although not emphasized in the presentation of the initial damage, recent investigation of steel structures uncovered severe failure of welded connections and with it, capacity reduction of entire structural systems in large buildings.

During the Northridge earthquake, several base isolated structures were subjected to large excitations, more than previously recorded. Their performance was as expected, i.e., controlled structural response with excellent protection of structural and nonstructural components. Their performance also indicated the importance of nonstructural details that might affect structural performance and the necessity for professional supervision of these details during construction. Although further evaluation of base isolated buildings is necessary, their generally excellent performance justifies their continuing application in structural design.

The Northridge earthquake displayed several combinations of large accelerations, horizontal and vertical, combined with large ground velocities in the vicinity of the epicenter. These combinations resulted in large spectral demands for lateral and vertical deformations in buildings. Such large deformations were not suitably accommodated by current design requirements. A reevaluation of current codes should be undertaken.

Finally, it seems that there is a discrepancy between the perception of damage by the engineering community, occupants, owners, and officials. Most damaged structures displayed permanent deformations which engineers expected according to the current design concepts. However, the severity of these deformations was never quantified and is perceived differently by all parties. A better quantification of damage, or performance, is necessary, and acceptable performance levels should be established and communicated to the owners, occupants, and officials. Socioeconomic issues need to be considered in quantifying performance. The effects of this earthquake, as unfortunate as they are, can and should be used as full-scale experimental data to calibrate future performance criteria.

8.3 Lifelines and Utilities

The Northridge earthquake revealed significant improvements in the seismic performance of lifelines since the 1971 San Fernando event. Improved lifeline equipment installed between 1971 and 1984 includes dead tank and bulk oil circuit breakers, steel and concrete tanks and polyethylene pipe. Also, improved emergency response plans were prepared and implemented by lifeline agencies during this period.

Customer water, gas and electrical service was disrupted for a small (5% to 20%) portion of the population impacted by the earthquake and for a relatively short period of time considering the intensity of the earthquake. Most of this disruption was due to distribution system damage and structural damage to residences and buildings. Redundancy was provided in distribution system networks and alternate supplies of electric power, gas and water from other sources were quickly available. Redundancy continues to play an important role in the restoration of lifeline services.

Lifeline structures and equipment which had been seismically upgraded from the 1971 San Fernando event performed well in the Northridge earthquake. Seismic upgrade of lifeline equipment, buildings and facilities is very costly and requires prioritizing, budgeting and some form of innovative financing. Research is needed to further improve the seismic performance of lifelines.

Water

Above ground storage tanks typically have one or two pipes, with valves, rigidly connected to the tank to allow filling and draining. In the Northridge earthquake, there were cases where the piping or valves broke due to differential movement between the tank and piping. Several methods have been developed for providing a more flexible connection between the tank and piping to withstand differential movement. Studies to identify cost-effective methods of preventing storage tank inlet/outlet piping damage due to differential movement should be undertaken.

Water supply lifelines use bell and spigot pipe almost exclusively for welded steel pipe. Bells are fabricated by an expansion process to provide the necessary large diameter. There were a number of instances in the Northridge earthquake where a bell was cracked at the curvature point where it changes diameter. Preliminary investigation indicates a need to study the seismic strength of welded steel bell and spigot joints to improve their seismic performance.

Sloshing of large basins in water filtration and water reclamation plants caused damage in the 1989 Loma Prieta earthquake and in the January 17 event. Although not critical, the damaged equipment can cause malfunction of other equipment. For example, sloshing caused jamming of the chain drive sludge scrapers in seven out of 44 final clarifiers at a water reclamation plant. There is a continuing need to consider sloshing in the design of mechanical equipment and baffles in large basins of water and wastewater treatment plants.

The Northridge earthquake demonstrated the vulnerability of lifelines within essential facilities, such as hospitals, fire stations and emergency operations centers. Roof top breaks in water lines and automatic sprinklers caused flooding in lower floors. Further, damage to roof top HVAC equipment caused malfunction of other systems within buildings. Internal lifelines in essential facilities require seismic design.

Natural Gas

The lessons learned as a result of the Northridge earthquake are similar to those in previous earthquakes. The principal lessons are:

- Oxy-acetylene welded steel transmission pipelines, constructed before 1932, are vulnerable to traveling ground wave effects which cause rupture and partial cracking at girth welds.

- Steel transmission pipelines constructed with either shielded or unshielded electric girth welds have generally performed well in areas of ground shaking. There are no instances of traveling ground wave damage to post-World War II pipelines, constructed with modern electric arc welding practices, during either the Northridge earthquake or other major earthquakes affecting Southern California.

- Both electric arc and oxy-acetylene welded pipelines are vulnerable to permanent ground deformations. During the Northridge earthquake, Lines 120 and 104 were damaged at zones of lateral spread and landslides, respectively. Both lines were constructed with electric arc welds.

- Polyethylene gas distribution piping has been remarkably resistant to earthquake effects. Relatively little damage to this type of piping has been reported as a result of the Northridge earthquake.

- Large facilities, such as the Aliso Canyon storage field, depend on internal water, gas, road, and electrical lifeline networks which are vulnerable to earthquake effects. Safe and reliable operation of such facilities requires an integrated assessment of earthquake integrity and retrofitting needs.

- The interaction between damaged water and gas pipelines was important in that simultaneous flooding and fire occurred at several locations. Further investigation of collocated pipelines and the interactive effects of damage in different systems is warranted.

There is the potential for fire if electrical service is restored in a damaged structure with an unidentified gas leak. Utility companies must coordinate efforts in the restoration of gas and electric service to avoid the potential for fire. Such coordination is especially critical during search and rescue operations. Similar efforts to coordinate are needed in restoration of water and sewer facilities.

In the Northridge earthquake, 133,000 customers unnecessarily turned off their gas service. These actions required gas company employees, supplemented by personnel from other gas companies, to make a time consuming piping, structure and gas appliance inspection before relighting the gas. Public education must emphasize that gas should not be turned off unless customers hear or smell gas or have physical damage to their structure or gas appliances.

Electric Power

This earthquake demonstrated the resiliency, and the importance of redundancy in electric power systems. Although the power systems suffered significant damage to key facilities, the vast majority of customers were restored to service within a couple of days. As in past earthquakes, power plants survived the event with minimal damage and were available to provide electricity following restoration of the electrical grid.

There continues to be a problem with failure of high voltage 230 and 500kv ceramic insulators. At a number of substations the insulators broke at the base, while the metal support structure was undamaged. There should be further study to improve the seismic performance of high voltage insulators.

Most emergency back up power supplies functioned in the earthquake, however there is a continuing need to regularly test these emergency generators under load to ensure adequate fuel supplies for a longer term commercial power outage, to provide for transferring fuel from the storage tank to the day tank when the electric pumps are out of service and, to enlarge the emergency generation capacity to cover other essential operations.

8.4 Nonstructural Building Elements

While structural damage accounted for much of the losses in the Northridge earthquake, it appears that nonstructural damage was responsible for a majority of the disruption, especially in essential facilities. California's hospitals and schools, which have been beneficiaries of tougher design standards over the past several decades, performed well structurally, but the performance of nonstructural components, especially in hospitals, was unacceptable. Over 30 hospitals suffered some level of degradation in service, though only one suffered serious structural damage.

Water damage caused by broken fire sprinkler systems, domestic water piping and HVAC piping was the major source of nonstructural damage in hospital facilities. Overturned oxygen tanks, ceiling damage, chemical spills and glass breakage also contributed to the need for evacuation of patients and service interruption. Obviously, disruption of utilities played a major role in loss of function in hospitals, but the significance of nonstructural damage was nevertheless great.

The cause of some of the more serious nonstructural damage was the interaction of components rather than individual component failures. Acoustic ceilings, particularly those designed and installed prior to 1976, apparently came into contact with sprinkler systems and the resulting damage was compounded by this interaction. Similarly, ductwork and water piping which traversed seismic joints resulted in significant damage and disruption. The potential for this component interaction should be an important design and construction consideration in repair, retrofit and new facility planning.

Northridge Hospital, located near the earthquake's epicenter, experienced some loss of function due to utility outages, but because of an aggressive program of nonstructural mitigation, did not experience the extent of disruption nor the length of time at reduced function as other facilities. This program worked and should be examined by medical centers in the region as well as hospitals in all areas of seismic risk.

Racks and Shelving

Based on the experience of the Northridge earthquake, the following items are recommended:

- More redundant rack member design and more stringent base plate and anchorage guidelines, including inspection of anchor bolt installation, should be used.
- Enforcement of posting of permissible pallet loads and improved warehousing practice.
- For installations with high value inventory, a design based on limiting lateral displacements should be used.

Water Sprinkler Systems

Sprinkler piping is highly vulnerable to damage from impact even with relatively light items such as ceiling tiles. In addition to piping bracing, the seismic design process must include careful analysis of seismic vulnerability of adjacent components and systems. As evidenced by this earthquake, sprinkler piping damage has a tremendous impact on losses to building interiors which include computers, magnetic and paper data, and inventory.

8.5 Emergency Response

The Northridge earthquake presented the most significant challenge to impacted local jurisdictions in twenty-three years. No disaster since the 1971 San Fernando earthquake has required a more comprehensive emergency response, nor has the Los Angeles metropolitan region or any region of the United States witnessed a comparable period of natural and human instigated disasters as that experienced over the past two years. In rapid succession, local, state and federal authorities have responded to the worst urban rioting in American history, the worst firestorms in recent history and the Northridge earthquake.

While it is difficult to find a silver lining in this succession of disasters, there were some serendipitous consequences. At the time of the earthquake, a State-Federal Disaster Field Office was already in existence to serve the recovery needs of the two previous events thus enabling a rapid mobilization of recovery resources even as search and rescue, fire suppression, building inspections and other response priorities were being addressed. In addition, local response readiness and planning had been twice tested to the limit and the roles were understood, the procedures familiar and the coordination among agencies fresh in memory. Nevertheless, the series has left local jurisdictions, especially the City and County of Los Angeles, with gaping budget deficits. The financial management of recovery from these serial disasters in the midst of a general economic downturn will be an enormous challenge.

For the first time in an earthquake disaster, state response authorities had access to near real-time estimates of shaking intensity, total dollar losses, losses by structural type, indirect losses and the numbers of casualties and displaced persons. Although these estimates were not available instantly, they appear to have been provided in a sufficiently timely manner to have influenced planning and policy formulation. Studies are currently underway to assess the application of these loss estimates to decision making in the Northridge earthquake. Rapid post-earthquake loss assessment is likely to be in great demand as the technology to provide rapid and accurate loss projections matures in the near future and is integrated into comprehensive emergency management decision support systems.

An emerging response innovation worthy of emulation in other disaster contexts is exemplified by two groups which were active in the Northridge earthquake, both were multi-disciplinary in character and both highly effective. The Urban Search and Rescue (US&R) Task Forces include personnel trained in search, rescue, emergency medicine, structural engineering, hazardous materials, specialized equipment operation and other fields. These self-sufficient units not only participated in the more difficult rescue operations in the earthquake but also assisted business owners in several locations by shoring up damaged and red tagged structures, allowing the removal of inventory for business resumption at alternate facilities.

Though less highly organized than the US&R Task Forces, the City of Los Angeles' "reassurance teams" were also quite effective. The reassurance teams were organized by the City's Department of Personnel to convince fearful residents who were camping in city parks that their homes had been inspected and were safe to reoccupy. The teams consisted of building inspectors, Red Cross workers, Housing Department representatives, translators, members of the clergy and mental health specialists. It appears that these teams were successful in reducing the displaced population and thereby the demand for emergency shelter and associated services.

8.6 Societal Impacts

The Northridge earthquake, like Loma Prieta, has provided an increased understanding of the range of impacts and issues that accompany major disasters occurring in urban areas. Emergency managers and disaster relief personnel are learning through experience how to deliver services in a complex and culturally diverse urban environment – an environment in which disaster impacts frequently exacerbate long standing social problems, making it difficult to adequately address the needs of victims. The Northridge earthquake contains many important lessons that need to be documented and incorporated into strategies for managing future disasters in urban settings.

While the earthquake stressed the emergency response system, it was not a catastrophic disaster for Southern California. Despite the widespread and dramatic damage that it caused, most of the built environment survived the earthquake intact, and most community institutions were not severely disrupted. At the same time, the Northridge event shows clearly that even moderate earthquakes, striking communities where mitigation and preparedness measures have been extensive, can generate immense losses when they occur in highly urbanized areas. Other communities and regions of the U.S. that have not addressed planning and mitigation to the same degree as Southern California would undoubtedly sustain catastrophic losses in a comparable or larger event.

Following a period of comparatively low seismic activity that was atypical for the region, moderate-sized earthquakes like the Northridge event are now occurring in California at the rate of approximately one every two years. Demographic changes and development trends over the past four decades have placed increasingly large numbers of people and structures at risk. Perhaps the major lessons of Northridge and other recent damaging earthquakes is that an even greater investment in seismic safety is needed to contain future losses.

SECTION 9
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APPENDIX A

CSMIP Strong Ground Motion Data

Station	Station	Structure	Epicenter	Trigger	Max. Acceleration			Record on
Name	No.	Type,Size*	Dist.**	Time#	Comp.	Grnd. (g)	Struct. (g)	Pg.
Tarzana	24436	Instr.	5	30:59.8	90	1.82		43
Cedar Hill Nursery A		shltr. H			Up	1.18		
					360	>1.06		
Van Nuys	24386	7-story	7	—	360	0.41	0.59	99
7-story Hotel		concrete bldg.			Up	0.30	—	
		(16 sensors)			270	0.47	0.59	
Sherman Oaks	24322	13-story	9	—	105	0.24	0.39	103
13-story Commercial		concrete bldg.			Up	0.18	—	
Bldg.		(15 sensors)			15	0.46	0.90	
Arleta	24087	1-story	10	—	90	0.35		45
Nordhoff Ave Fire Sta.		bldg.			Up	0.59		
					360	0.29		
Sylmar	24514	Small 1-story	16	31:00.4	360	0.91		43
County Hospital		bldg.			Up	0.60		
Parking Lot					90	0.61		
Sylmar	24514	6-story steel/	16	31:00.4	356	0.82	2.31	107
6-story County Hospital		concrete bldg.			Up	0.34	—	
		(13 sensors)			86	0.42	0.79	
Pacoima	24088	1-story	18	30:59.5	90	0.30		45
Kagel Canyon		bldg.			Up	0.19		
					360	0.44		
Los Angeles	24688	Instr.	18	31:00.4	90	0.32		71
UCLA Grounds		shltr. H			Up	0.29		
					360	0.66		
Los Angeles	24231	7-story steel/	18	—	90	0.25	0.46	115
7-story UCLA		concrete bldg.			Up	0.25	—	
Math-Science Bldg.		(12 sensors)			360	0.29	0.77	
North Hollywood	24464	20-story	19	31:00.5±	90	0.13	0.34	111
20-story Hotel		concrete bldg.			Up	0.15	—	
		(16 sensors)			360	0.33	0.66	
Pacoima Reservoir	24207	Concrete	19	—	360	0.54	1.76	255
Pacoima Dam		arch dam			Up	0.43	>1.60	
		(20 sensors)			270	0.49	2.01	
Pacoima Dam	24207	Instr.	19	—	265	0.44		44
Downstream		shltr. D			Up	0.20		
					175	0.42		
Pacoima Dam	24207	Instr.	19	31:00.5	205	1.53		44
Upper Left Abutment		shltr. A			Up	1.39		
					115	>1.22		

CSMIP Strong-Motion Data - Northridge Earthquake (Continued)

Station Name	Station No.	Structure Type,Size*	Epicenter Dist.**	Trigger Time#	Comp.	Max. Acceleration Grnd. (g)	Max. Acceleration Struct. (g)	Record on Pg.
Century City LACC North	24389	Instr. shltr. H	20	31:00.8	90	0.27		53
					Up	0.15		
					360	0.24		
Century City LACC South	24390	Instr. shltr. H	20	31:00.8	90	0.23		53
					Up	0.10		
					360	0.35		
Newhall LA County Fire Sta.	24279	1-story bldg.	20	31:00±	90	0.63		46
					Up	0.62		
					360	0.61		
Los Angeles 19-story Office Bldg.	24643	19-story steel bldg. (15 sensors)	20	30:56.1	314	0.20	0.65	121
					Up	0.13	—	
					44	0.32	0.53	
Los Angeles 3-story Commercial Bldg.	24332	3-story steel/ concrete bldg. (15 sensors)	20	—	321	0.33	0.66	125
					Up	0.15	0.26	
					51	0.33	0.97	
Burbank 10-story Residential Bldg.	24385	10-story concrete bldg. (16 sensors)	21	—	45	0.35	0.79	129
					Up	0.13	—	
					315	0.28	0.54	
Burbank 6-story Commercial Bldg.	24370	6-story steel Bldg. (13 sensors)	22	—	135	0.24	0.28	118
					Up	0.15	0.15	
					45	0.35	0.49	
Los Angeles I10/405 Interchange	24670	Curved concrete bridge (7 sensors)	22	30:56.6	T	—	1.79	259
					Up	—	1.83	
					L	—	1.00	
Santa Monica City Hall Grounds	24538	Instr. shltr. H	23	31:02.9	90	0.93		47
					Up	0.25		
					360	0.42		
Los Angeles Hollywood Storage Bldg. Grounds	24303	Instr. shltr. H	23	—	90	0.24		47
					Up	0.19		
					360	0.41		
Los Angeles Hollywood Storage Bldg.	24236	14-story concrete bldg. (12 sensors)	23	31:01.2	90	0.21	1.61	133
					Up	0.11	—	
					360	0.29	0.51	
Wood Ranch Reservoir Main Dam and Dikes	24251	Earth dam (12 sensors)	26	31:01.6	335	—	0.28	280
					Up	—	0.18	
					245	—	0.39	
Los Angeles Baldwin Hills	24157	Instr. shltr. A	28	—	90	0.24		68
					Up	0.10		
					360	0.17		

CSMIP Strong-Motion Data - Northridge Earthquake (Continued)

Station Name	Station No.	Structure Type,Size*	Epicenter Dist.**	Trigger Time#	Comp.	Max. Acceleration Grnd. (g)	 Struct. (g)	Record on Pg.
Los Angeles	24612	Instr.	31	—	90	0.10		70
Pico & Sentous		shltr. H			Up	0.07		
					180	0.19		
Los Angeles	24655	6-story	31	30:57.9	30	0.29	1.21	147
6-story Parking		concrete bldg.			Up	0.22	0.52	
Structure		(14 sensors)			120	0.15	0.31	
Los Angeles	24652	6-story	31	30:57.8	345	0.20	0.29	151
6-story Office Bldg.		steel bldg.			Up	0.08	0.18	
		(14 sensors)			75	0.24	0.59	
Los Angeles	24602	52-story	31	30:58.5	355	0.15	0.41	159
52-story Office Bldg.		steel bldg.			Up	0.11	—	
		(20 sensors)			85	0.11	0.23	
Los Angeles	24611	Instr.	32	30:58.6	90	0.13		70
Temple & Hope		shltr. H			Up	0.10		
					180	0.19		
Los Angeles	24579	9-story	32	30:58.2	40	0.18	0.32	189
9-story Office Bldg.		concrete/URM			Up	0.12	—	
		bldg. (18 sensors)			310	0.13	0.34	
Los Angeles	24567	13-story steel/	32	31:01.6	223	0.18	0.27	192
13-story Office Bldg.		concrete/URM bldg.			Up	0.07	—	
		(15 sensors)			313	0.17	0.37	
Los Angeles	24569	15-story	32	30:58.9	43	0.21	0.52	194
15-story Government		steel bldg.			Up	0.07	—	
Office Bldg.		(15 sensors)			313	0.14	0.23	
Los Angeles	24601	17-story	32	30:58.6	220	0.26	0.46	155
17-story Residential		concrete bldg.			Up	0.08	—	
Bldg.		(14 sensors)			130	0.19	0.58	
Los Angeles	24629	54-story	32	30:58.1	40	0.14	0.19	198
54-story Office		steel bldg.			Up	0.09	—	
Bldg.		(20 sensors)			130	0.09	0.14	
Malibu	24396	1-story bldg.	32	31:02.0	90	0.13		71
Point Dume					Up	0.10		
					360	0.10		
Moorpark	24283	Small garage	33	31:02.7	180	0.30		48
					Up	0.15		
					90	0.19		
Lake Piru	24280	Earth dam	34	31:02.9	265	0.21	0.27	286
Santa Felicia Dam		(6 sensors)			Up	0.13	0.13	
					175	0.27	0.30	

CSMIP Strong-Motion Data - Northridge Earthquake (Continued)

					Max. Acceleration			
Station Name	Station No.	Structure Type,Size*	Epicenter Dist.**	Trigger Time#	Comp.	Grnd. (g)	Struct. (g)	Record on Pg.
El Segundo	14654	14-story	35	30:58.8	315	0.09	0.25	165
14-story Office Bldg.		steel bldg.			Up	0.04	0.17	
		(16 sensors)			45	0.13	0.22	
Los Angeles	24463	5-story concrete	36	---	350	0.26	0.29	184
5-story Warehouse		bldg.			Up	0.08	---	
		(13 sensors)			260	0.20	0.25	
Los Angeles	24605	7-story isolated	36	30:57.8	5	0.37	0.21	141
7-story University		steel bldg.			Up	0.09	0.13	
Hospital		(24 sensors)			95	0.17	0.19	
Los Angeles	24605	Instr.	36	30:57.8	5	0.49		48
University Hospital		shltr. D			Up	0.12		
Grounds					95	0.22		
Pasadena	24541	6-story	37	31:03.0	90	0.12	0.17	206
6-story Office Bldg.		steel/URM			Up	0.09	---	
		bldg.(16 sensors)			360	0.17	0.21	
Pasadena	24571	9-story	37	31:01.2	90	0.16	0.19	209
9-story Commercial		concrete bldg.			Up	0.12	—	
Bldg.		(15 sensors)			180	0.19	0.29	
Pasadena	24546	12-story steel	37	31:01.0	360	—	0.32	212
12-story Commercial/		bldg.			Up	0.09	—	
Office Bldg.		(15 sensors)			270	—	0.20	
Pasadena	24566	12-story	37	31:01.0	180	0.23	0.31	214
12-story Office Bldg.		steel bldg.			Up	0.10	---	
		(15 sensors)			270	0.14	0.18	
Vasquez Rocks Park	24047	Instr.	37	31:02.7	90	0.15		92
		Shltr. A			Up	0.09		
					360	0.16		
Los Angeles	24468	8-story	38	---	180	0.13	0.25	186
8-story CSULA Admin.		concrete bldg.			Up	0.06	0.17	
Bldg.		(16 sensors)			90	0.17	0.22	
Los Angeles	24592	Instr.	38	30:58.3	90	0.26		69
City Terrace		shltr. H			Up	0.13		
					180	0.32		
Los Angeles	24580	2-story isolated	38	30:58.7	40	0.18	0.09	137
2-story Fire Command		steel bldg.			Up	0.11	0.30	
Control Bldg.		(16 sensors)			310	0.22	0.35	
Los Angeles	24400	1-story	39	31:04.8	90	0.36		69
Obregon Park		bldg.			Up	0.11		
					360	0.42		

CSMIP Strong-Motion Data - Northridge Earthquake (Continued)

						Max. Acceleration		
Station Name	Station No.	Structure Type,Size*	Epicenter Dist.**	Trigger Time#	Comp.	Grnd. (g)	Struct. (g)	Record on Pg.
Alhambra	24461	1-story	39	31:04.4	90	0.12		49
Fremont School		bldg.			Up	0.07		
					360	0.09		
San Marino	24401	1-story	39	31:04.5	90	0.12		86
Southwestern Academy		bldg.			Up	0.09		
					360	0.16		
Lake Hughes 12A	24607	Instr.	40	31:00.4	90	0.18		61
		shltr. H			Up	0.12		
					180	0.26		
Castaic	24278	1-story	41	31:03.4	90	0.59		46
Old Ridge Route		bldg.			Up	0.25		
					360	0.54		
Los Angeles	14403	1-story	41	31:04.1	90	0.20		68
116th St. School		bldg.			Up	0.06		
					360	0.15		
Inglewood	14196	Instr.	42	31:06.2	90	0.12		58
Union Oil Yard		shltr. A			Up	0.06		
					360	0.10		
Lake Hughes #9	24272	Instr.	44	31:03.9	90	0.24		59
		shltr. H			Up	0.09		
					360	0.17		
Mt. Wilson	24399	Seismic	45	31:04.5	90	0.14		73
Caltech Seismic		vault			Up	0.11		
Station					360	0.23		
Downey	14368	1-story	47	—	90	0.17		54
County Maint. Bldg.		bldg.			Up	0.14		
					360	0.23		
Lake Hughes #4	24469	Instr.	49	31:04.9	90	0.10		60
Camp Mendenhall		shltr. A			Up	0.06		
(near water tank)					360	0.06		
Lake Hughes #4B	24523	Instr.	49	31:04.7	90	0.07		60
Camp Mendenhall		shltr. A			Up	0.05		
					360	0.05		
Point Mugu	25148	1-story bldg.	50	31:06.3	90	0.22		79
Laguna Peak					Up	0.08		
					360	0.14		
Camarillo	25282	1-story bldg.	50	—	270	0.11		52
					Up	0.05		
					180	0.12		

CSMIP Strong-Motion Data - Northridge Earthquake (Continued)

					Max. Acceleration			
Station Name	Station No.	Structure Type,Size*	Epicenter Dist.**	Trigger Time#	Comp.	Grnd. (g)	Struct. (g)	Record on Pg.
Rolling Hills Estates	14405	1-story bldg.	50	---	90	0.12		82
Rancho Vista School					Up	0.05		
					360	0.11		
Leona Valley #1	24305	Instr.	51	31:05.8	90	0.09		63
		shltr. H			Up	0.05		
					360	0.10		
Leona Valley #2	24306	Instr.	51	---	90	0.07		63
		shltr. H			Up	0.07		
					360	0.10		
Leona Valley #3	24307	Instr.	51	31:06.2	90	0.12		64
		shltr. H			Up	0.06		
					360	0.08		
Leona Valley #4	24308	Instr.	51	31:06.2	90	0.07		64
		shltr. H			Up	0.06		
					360	0.08		
Leona Valley #5	24055	Instr.	51	31:05.2	90	0.09		65
Ritter Ranch		shltr. H			Up	0.10		
					360	0.15		
Leona Valley #6	24309	Instr.	52	31:05.1	90	0.18		65
		shltr. H			Up	0.07		
					360	0.14		
Anaverde Valley	24576	Instr.	52	31:02.3	90	0.04		50
City Ranch		shltr. H			Up	0.04		
					180	0.06		
Long Beach	14242	Instr.	52	31:08.1	90	0.08		67
Rancho Los Cerritos		shltr. H			Up	0.05		
					360	0.07		
Elizabeth Lake	24575	Instr.	52	31:02.5	90	0.16		55
		shltr. H			Up	0.05		
					180	0.11		
Rancho Palos Verdes	14404	1-story	53	31:07.6	90	0.06		80
Hawthorne Blvd.		bldg.			Up	0.04		
					360	0.08		
Lake Hughes #1	24271	1-story	53	31:05.2	90	0.08		59
Fire Station #78		bldg.			Up	0.10		
					360	0.09		
Cogswell Reservoir	23210	Earth dam	53	31:05.3	155	0.15	0.32	283
Cogswell Dam		(9 sensors)			Up	0.07	0.28	
					65	0.11	0.35	

CSMIP Strong-Motion Data - Northridge Earthquake (Continued)

						Max. Acceleration		
Station Name	Station No.	Structure Type,Size*	Epicenter Dist.**	Trigger Time#	Comp.	Grnd. (g)	Struct. (g)	Record on Pg.
Whittier	14606	8-story reinf.	53	31:01.4	360	0.19	0.49	250
8-story Hotel		masonry bldg.			Up	0.11	—	
		(12 sensors)			90	0.11	0.23	
Point Mugu	25147	Radar dome	54	31:06.3	90	0.17		79
Naval Air Station					Up	0.07		
					360	0.19		
Palmdale	24232	4-story reinf.	56	—	140	0.05	0.11	204
4-story Hotel		masonry bldg.			Up	0.06	0.05	
		(9 sensors)			50	0.09	0.13	
Palmdale	24521	Instr.	56	31:03.7	270	0.07		77
Hwy 14 & Palmdale Blvd		shltr. H			Up	0.04		
					360	0.06		
Fairmont Reservoir	24270	1-story	56	31:06.1	90	0.04		--
Fairmont Dam		bldg.			Up	0.03		
Right Abutment					360	0.06		
Los Angeles	14406	Suspension	57	31:07.4	190	0.19	0.65	263
Vincent Thomas Bridge		bridge			Up	0.08	0.44	
		(26 sensors)			100	0.25	0.55	
San Pedro	14159	1-story	58	—	90	0.10		89
Palos Verdes		bldg.			Up	0.07		
					360	0.11		
Long Beach	14560	Instr.	58	31:10.3	90	0.06		66
City Hall Grounds		shltr. H			Up	0.03		
					360	0.06		
Long Beach	14533	15-story	58	31:10.3	135	0.04	0.05	177
15-story Government		steel bldg.			Up	0.03	0.05	
Office Bldg.		(16 sensors)			45	0.03	0.06	
Long Beach	14323	7-story	59	31:15.0	90	0.07	0.13	180
7-story Office Bldg.		steel bldg.			Up	0.02	—	
		(18 sensors)			360	0.06	0.09	
Long Beach	14395	Instr.	60	31:11.9	90	0.06		66
Harbor Plaza		Shltr. H			Up	0.03		
					360	0.06		
Littlerock	23595	Instr.	60	31:01.3	90	0.07		61
Brainard Canyon		shltr. H			Up	0.04		
					180	0.06		
Long Beach	14241	Instr.	61	31:11.6	90	0.06		67
Recreation Park		shltr. H			Up	0.03		
					360	0.04		

CSMIP Strong-Motion Data - Northridge Earthquake (Continued)

						Max. Acceleration		
Station Name	Station No.	Structure Type,Size*	Epicenter Dist.**	Trigger Time#	Comp.	Grnd. (g)	Struct. (g)	Record on Pg.
Long Beach	14311	5-story	62	—	360	0.04	—	--
5-story CSULB Engineering		concrete bldg.			Up	0.04	—	
Bldg.		(9 sensors)			90	0.09	—	
Sandberg	24644	Instr.	62	31:01.6	90	0.09		88
Bald Mountain		Shltr. H			Up	0.04		
					180	0.10		
Port Hueneme	25281	1-story	62	31:09.3	180	0.09		80
		bldg.			Up	0.04		
					90	0.10		
Antelope Buttes	24310	Instr.	63	31:06.7	90	0.07		50
		Shltr. H			Up	0.03		
					360	0.05		
Lancaster	24517	3-story reinf.	64	—	115	0.05	0.15	172
3-story Office Bldg.		masonry bldg.			Up	0.04	—	
		(13 sensors)			25	0.07	0.09	
Lancaster	24526	Instr.	64	31:07.1	115	0.08		62
15th & J		shltr. H			Up	0.11		
					25	0.08		
Lancaster	24609	5-story	64	31:01.8	25	0.07	0.28	174
5-story Hospital		steel bldg.			Up	0.04	—	
		(12 sensors)			295	0.06	0.15	
Lancaster	24474	Control	66	31:07.5	60	0.08	0.20	299
Airport Control Tower		Tower			Up	0.04	—	
		(9 sensors)			330	0.08	0.15	
Lancaster	24475	Instr.	66	31:07.6	90	0.07		62
Fox Airfield		shltr. H			Up	0.05		
Grounds					360	0.09		
Seal Beach	14578	8-story isolated	66	31:04.0	90	0.08	0.15	242
8-story Office Bldg.		concrete bldg.			Up	0.02	0.16	
		(28 sensors)			360	0.05	0.12	
Seal Beach	14578	Instr.	66	31:04.0	90	0.09		89
8-story Office Bldg.		shltr. H			Up	0.04		
Parking Lot					360	0.06		
Big Dalton Reservoir	23247	Concrete dam	68	31:09.7	20	—	0.09	288
Big Dalton Dam		(9 sensors)			Up	—	0.04	
					110	—	0.18	
Puddingstone Reservoir	23328	Earth dam	69	31:11.4	333	0.05	0.21	291
Puddingstone Dam		(15 sensors)			Up	—	0.07	
					243	0.04	0.12	

CSMIP Strong-Motion Data - Northridge Earthquake (Continued)

Station Name	Station No.	Structure Type,Size*	Epicenter Dist.**	Trigger Time#	Comp.	Max. Acceleration		Record on Pg.
						Grnd. (g)	Struct. (g)	
Ventura	25339	12-story	70	---	360	0.12	0.30	247
12-story Hotel		concrete bldg.			Up	0.04	---	
		(15 sensors)			90	0.07	0.31	
Ventura	25340	Instr.	70	31:10.2	90	0.06		93
Harbor & California		Shltr. H			Up	0.02		
					360	0.07		
Neenach	24586	Instr.	71	31:06.1	90	0.06		75
Sacatara Creek		shltr. H			Up	0.05		
					180	0.07		
Rosamond	24274	Instr.	73	31:09.4	90	0.05		83
Godde Ranch		shltr. H			Up	0.03		
					360	0.05		
Pomona	23525	Instr.	75	31:09.8	90	0.05		78
4th & Locust		shltr. H			Up	0.04		
					360	0.05		
Pomona	23511	2-story	75	31:10.4	360	0.05	0.15	216
2-story Commercial		concrete bldg.			Up	0.04	---	
Bldg.		(10 sensors)			270	0.06	0.22	
Pomona	23544	6-story	75	31:09.2	270	0.07	0.16	222
6-story Commercial		concrete/URM			Up	0.03	---	
Bldg.		bldg.(12 sensors)			180	0.04	0.15	
Wheeler Gorge	25090	1-story	75	---	90	0.03		93
		bldg.			Up	0.03		
					360	0.02		
Wrightwood	23590	Instr.	76	31:06.0	90	0.06		94
Jackson Flat		shltr. H			Up	0.03		
					180	0.04		
Anacapa Island	25169	1-story	79	---	360	0.07		49
		bldg.			Up	0.02		
					270	0.04		
Huntington Beach	13197	1-story	79	---	90	0.08		58
Lake Street Fire Station		bldg.			Up	0.03		
					360	0.10		
Rosamond	24092	1-story	80	---	90	0.04		83
Airport		bldg.			Up	0.03		
					360	0.08		
Lockwood Valley	25029	1-story	81	31:12.2	90	0.04		—
		bldg.			Up	0.02		
					360	0.03		

CSMIP Strong-Motion Data - Northridge Earthquake (Continued)

						Max. Acceleration		
Station Name	Station No.	Structure Type,Size*	Epicenter Dist.**	Trigger Time#	Comp.	Grnd. (g)	Struct. (g)	Record on Pg.
Mt. Baldy Elementary School	23572	Instr. shltr. H	81	31:06.3	90	0.08		72
					Up	0.04		
					180	0.07		
Wrightwood Swarthout Valley	23574	Instr. shltr. H	83	31:06.0	90	0.05		95
					Up	0.04		
					180	0.06		
Cuddy Valley	25051	Instr. Shltr. A	85	31:12.7	90	0.05		52
					Up	0.02		
					360	0.05		
Featherly Park Park Maint. Bldg.	13122	1-story bldg.	86	—	90	0.12		55
					Up	0.03		
					360	0.11		
Newport Beach 11-story Hospital	13589	11-story concrete bldg. (18 sensors)	86	31:08.3	335	0.05	0.19	201
					Up	0.03	0.05	
					65	0.08	0.26	
Newport Beach Newport Blvd. & Coast Hwy	13610	Instr. Shltr. H	86	31:07.3	90	0.11		76
					Up	0.02		
					180	0.08		
Palmdale Black Butte	23585	Instr. shltr. H	86	31:07.7	90	0.03		77
					Up	0.02		
					180	0.03		
Newport Beach Irvine Ave. Fire Station	13160	1-story bldg.	87	—	90	0.07		76
					Up	0.02		
					360	0.04		
Rancho Cucamonga Deer Canyon	23598	Instr. shltr. H	89	31:06.9	90	0.07		81
					Up	0.03		
					180	0.05		
Rancho Cucamonga Law & Justice Center Parking Lot	23497	Instr. shltr. D	90	31:15.1	360	0.08		81
					Up	0.03		
					90	0.05		
Rancho Cucamonga Law and Justice Center	23497	4-story base- isolated bldg. (16 sensors)	90	31:15.1	360	0.05	0.09	219
					Up	0.03	0.03	
					90	0.03	0.10	
Irvine 8-story UCI Engineering Bldg.	13329	8-story steel/ concrete bldg. (12 sensors)	90	—	225	0.05	0.09	171
					Up	0.02	—	
					135	0.04	0.21	
Mojave Hwy 14 & Backus Rd	24269	Instr. shltr. H	90	31:13.4	90	0.06		74
					Up	0.03		
					360	0.03		

CSMIP Strong-Motion Data - Northridge Earthquake (Continued)

Station Name	Station No.	Structure Type,Size*	Epicenter Dist.**	Trigger Time#	Comp.	Max. Acceleration Grnd. (g)	Max. Acceleration Struct. (g)	Record on Pg.
Santa Catalina Island	14165	1-story bldg.	90	31:27.3	360	0.04		91
					Up	0.02		
					270	0.05		
Ozena	25164	1-story bldg.	91	31:17.2	90	0.04		--
					Up	0.02		
					360	0.04		
Wrightwood Nielson Ranch	23573	Instr. shltr. H	93	31:08.8	90	0.04		94
					Up	0.02		
					180	0.04		
Etiwanda Power Plant	23466	Steam generating plant (12 sensors)	94	31:18.1	180	0.07	0.11	297
					Up	0.03	0.13	
					90	0.05	0.10	
Jameson Lake Juncal Dam A	25291	Concrete arch dam (9 sensors)	94	31:26.1	160	0.03	0.01	--
					Up	0.01	0.01	
					70	0.05	0.05	
Jameson Lake Juncal Dam B	25295	Multiple arch dam (9 sensors)	94	—	150	—	0.07	--
					Up	—	0.02	
					60	—	0.05	
Mojave Oak Creek Canyon	34237	Instr. Shltr. A	94	31:15.1	90	0.07		74
					Up	0.03		
					360	0.05		
Phelan Wilson Ranch Road	23597	Instr. shltr. H	98	31:08.8	90	0.05		78
					Up	0.04		
					180	0.06		
Mojave Hwys 14 & 58	34093	1-story bldg.	101	—	90	0.07		73
					Up	0.03		
					360	0.04		
Cummings Valley	34030	Instr. Shltr. A	102	31:26.3	90	0.02		--
					Up	0.01		
					360	0.01		
Tehachapi Valley Blvd & Curry St.	34487	Instr. shltr. H	102	31:14.8	90	0.06		92
					Up	0.03		
					360	0.06		
Devore I15/215 Interchange Bridge	23650	Concrete bridge (6 sensors)	104	31:11.7	T	0.08	0.24	274
					Up	0.03	0.05	
					L	0.07	0.07	
Riverside Airport	13123	1-story bldg.	105		270	0.07		82
					Up	0.03		
					180	0.06		

CSMIP Strong-Motion Data - Northridge Earthquake (Continued)

Station Name	Station No.	Structure Type,Size*	Epicenter Dist.**	Trigger Time#	Max. Acceleration Comp.	Max. Acceleration Grnd. (g)	Max. Acceleration Struct. (g)	Record on Pg.
Arvin	34107	Instr. Shltr. A	106	31:17.1	90	0.04		51
					Up	0.02		
					360	0.03		
Lake Mathews Main Dam	13313	Earth dam (6 sensors)	108	31:19.5	350	---	0.12	295
					Up	---	0.07	
					260	---	0.15	
Lake Mathews Dike 1	13326	Earth dam (9 sensors)	109	31:16.6	75	0.04	—	296
					Up	0.02	---	
					345	0.04	—	
Santa Barbara 4-story Office Bldg.	25302	4-story steel/ concrete bldg. (9 sensors)	109	—	315	0.03	0.10	-
					Up	0.01	—	
					45	0.03	0.14	
Gibraltar Reservoir Gibraltar Dam	25255	Concrete arch dam (16 sensors)	111	31:17.1	275	0.03	0.05	-
					Up	0.02	0.02	
					185	0.02	0.04	
Riverside 13-story Government Office Bldg.	13312	13-story steel/concrete (15 sensors)	111	---	30	0.04	0.14	227
					Up	0.03	---	
					120	0.05	0.15	
Riverside 2-story Govt. Office Bldg.	13620	2-story concrete bldg. (12 sensors)	111	31:12.4	305	0.05	0.09	226
					Up	0.03	—	
					35	0.05	0.16	
Colton 1-story School Gym	23540	1-story tilt-up bldg. (13 sensors)	112	31:16.7	5	0.04	0.10	168
					Up	0.04	—	
					95	—	0.23	
San Bernardino 5-story CSUSB Library	23285	5-story concrete bldg. (10 sensors)	112	—	215	0.03	0.09	229
					Up	0.02	---	
					125	0.04	0.21	
San Bernardino CSUSB Grounds	23672	Instr. Shltr. H	113	31:13.7	360	0.03		85
					Up	0.02		
					90	0.07		
San Bernardino 5-story Hospital	23634	5-story steel bldg. (12 sensors)	113	31:15.0	2	0.08	0.35	236
					Up	0.04	—	
					92	0.08	0.32	
Hesperia 4th & Palm	23583	Instr. shltr. H	115		90	0.04		57
					Up	0.03		
					180	0.04		
Santa Barbara Hwy 101 & State	25423	1-story bldg.	115	—	90	0.03		91
					Up	0.02		
					360	0.05		

CSMIP Strong-Motion Data - Northridge Earthquake (Continued)

Station Name	Station No.	Structure Type,Size*	Epicenter Dist.**	Trigger Time#	Comp.	Max. Acceleration Grnd. (g)	Struct. (g)	Record on Pg.
San Bernardino	23622	1-story	116	31:12.2	180	0.05	0.15	232
1-story Commercial		concrete/URM			Up	0.02	---	
Bldg.		bldg.(10 sensors)			90	0.08	0.07	
San Bernardino	23522	Instr.	116	31:20.1	270	0.04		86
2nd & Arrowhead		shltr. H			Up	0.02		
					360	0.04		
San Bernardino	23515	9-story	116	31:21.8	180	0.04	0.06	240
9-story Commercial		steel bldg.			Up	0.02	---	
Bldg.		(13 sensors)			90	0.05	0.07	
San Bernardino	23542	Instr.	116	---	90	0.08		85
E & Hospitality		shltr. H			Up	0.04		
					180	0.10		
San Bernardino	23631	Curved concrete	116	31:14.4	T	0.13	0.47	269
I10/215 Interchange		bridge			Up	0.04	0.31	
		(34 sensors)			L	0.08	0.16	
San Bernardino	23516	3-story steel	117	31:16.5	360	0.06	0.14	234
3-story Office Bldg.		bldg.			Up	0.03	---	
		(13 sensors)			270	0.08	0.20	
San Bernardino	23287	6-story concrete	118	---	180	0.06	0.23	238
6-story Hotel		bldg.			Up	0.02	---	
		(9 sensors)			90	0.07	0.15	
Boron	33083	1-story	120	---	90	0.09		51
Fire Station		bldg.			Up	0.05		
					360	0.13		
Cuyama Valley	25052	Instr.	121	31:18.5	90	0.04		54
		Shltr. A			Up	0.02		
					360	0.06		
Santa Barbara	25213	3-story	122	31:22.3	360	0.04	0.16	241
3-story UCSB Office Bldg.		concrete bldg.			Up	0.03	---	
		(9 sensors)			90	0.04	0.09	
Santa Barbara	25392	Instr.	122	31:21.6	90	0.04		90
UCSB Grounds		Shltr. H			Up	0.02		
					360	0.04		
Santa Barbara	25091	1-story	123	---	90	0.07		90
UCSB Goleta		bldg.			Up	0.05		
					360	0.08		
Redlands	23495	1-story concrete	123	31:18.7	360	0.07	0.20	224
1-story Warehouse		tilt-up bldg.			Up	0.02	---	
		(12 sensors)			90	0.05	0.20	

CSMIP Strong-Motion Data - Northridge Earthquake (Continued)

Station Name	Station No.	Structure Type,Size*	Epicenter Dist.**	Trigger Time#	Comp.	Max. Acceleration Grnd. (g)	Max. Acceleration Struct. (g)	Record on Pg.
Redlands	23481	7-story steel	127	31:20.9	180	0.06	0.10	225
7-story Commercial		bldg.			Up	0.02	---	
Bldg.		(13 sensors)			270	0.04	0.07	
Beaumont	12649	Concrete	146	31:18.8	183	0.04	0.09	276
I10/60 Interchange Bridge		bridge			Up	0.02	0.03	
		(6 sensors)			273	0.04	0.07	
Murrieta Hot Springs	13198	Instr.	147	31:37.5	90	0.02		--
Collins Ranch		shltr. A			Up	0.02		
					360	0.02		
Winchester	13199	Instr.	148	31:42.7	90	0.01		--
Bergman Ranch		shltr. A			Up	0.02		
					360	0.01		
Hemet	13660	Instr.	150	31:19.4	360	0.06		56
Ryan Airfield		Shltr. H			Up	0.03		
					90	0.05		
Temecula	13172	Instr.	151	31:26.6	90	0.04		--
6th & Mercedes		shltr. H			Up	0.04		
					360	0.03		
Hemet	12266	1-story	154	---	360	0.05	0.10	--
1-story Library		bldg.			Up	0.04	---	
		(6 sensors)			270	0.05	0.10	
Hemet	12331	1-story	154	31:40.8	90	0.05		57
Stetson Ave Fire		bldg.			Up	0.03		
Station					360	0.06		
San Jacinto	12673	Instr.	154	31:19.8	360	0.08		87
CDF Fire Station		Shltr. H			Up	0.02		
					90	0.10		
San Jacinto	12202	1-story	154	31:41.2	90	0.05		88
Valley Cemetery		bldg.			Up	0.05		
					360	0.04		
Hemet	12267	4-story	155	---	315	0.05	0.10	170
4-story Hospital		concrete bldg.			Up	0.06	---	
		(10 sensors)			225	0.05	0.07	
San Jacinto	12618	Instr.	160	31:37.8	90	0.02		87
Soboba A		Shltr. H			Up	0.02		
					180	0.02		

CSMIP Strong-Motion Data - Northridge Earthquake (Continued)

						Max. Acceleration		
Station Name	Station No.	Structure Type,Size*	Epicenter Dist.**	Trigger Time#	Comp.	Grnd. (g)	Struct. (g)	Record on Pg.
Heart Bar State Park	22T04	1-story	161	31:39.6	90	0.02		56
		bldg.			Up	0.01		
					180	0.01		
Banning	12674	Instr.	163	31:42.0	360	0.01		—
Twin Pines Rd.		Shltr. H			Up	0.004		
					90	0.01		
Sage	12636	1-story	165	—	90	0.02		84
Fire Station		bldg.			Up	0.01		
					180	0.03		
Yermo	22074	1-story	176	—	360	0.04		95
Fire Station		bldg.			Up	0.02		
					270	0.04		
North Palm Springs	12666	Steel	181	—	T	0.02	0.11	278
110/62 Interchange Bridge		bridge			Up	0.01	—	
		(7 sensors)			L	0.02	0.08	
Yucca Valley	22T01	1-story	198	—	90	0.01		—
		bldg.			Up	0.01		
					180	0.01		
Indio	12543	Instr.	221	32:16.3	274	0.01		—
Riverside Co.		shltr. H			Up	0.01		
Fairgrounds					4	0.01		
Indio	12493	4-story	221	—	360	—	0.05	—
4-story Govt. Office		concrete bldg.			Up	—	—	
Bldg.		(9 sensors)			90	—	0.02	
Desert Shores	12626	Instr.	244	32:03.6	90	0.01		—
		shltr. H			Up	0.004		
					180	0.01		
Mecca	11625	Instr.	247	32:04.8	90	0.02		72
CVWD Yard		shltr. H			Up	0.01		
					180	0.02		
North Shore	11613	Instr.	256	32:05.4	90	0.03		75
Salton Sea State		shltr. H			Up	0.01		
Park HQ					180	0.03		
Salton City	11628	Instr.	258	32:08.1	90	0.02		84
		shltr. H			Up	0.005		
					180	0.02		

CSMIP Strong-Motion Data - Northridge Earthquake (Continued)

Station Name	Station No.	Structure Type,Size*	Epicenter Dist.**	Trigger Time#	Comp.	Max. Acceleration Grnd. (g)	Max. Acceleration Struct. (g)	Record on Pg.
North Shore Durmid	11591	Instr. shltr. H	266	32:10.9	90	0.01		--
					Up	0.01		
					180	0.01		
Bombay Beach Bertram	11627	Instr. Shltr. H	271	32:16.9	90	0.01		--
					Up	0.004		
					180	0.01		

Footnotes:

* - Instrument shelter types:
Instr. shltr. A - small prefabricated metal building
Instr. shltr. D - small metal box
Instr. shltr. H - small fiberglass shelter

** - Distance (in km) relative to the presently estimated (USGS, CIT) epicenter at 34.209N, 118.541W.

\# - Accelerograph trigger time, when present, is in minutes and seconds after 12:00:00 UTC on 17 January 1994.

APPENDIX B

USGS Strong Ground Motion Data

MAP INDEX NO.	STATION LOCATION [OWNER]	COORDINATES (Lat. ° N Long. ° W)	EPICENTRAL DISTANCE (km)	ACCELERATION DIRECTION (Degrees)	ACCELERATION MAXIMUM (g)	RECORD PAGE NO.
1	Los Angeles	34.185	5	360	0.48	53
	6301 Owensmouth Ave.	118.584		Up	0.48	
	[CODE] Roof (12)			270	0.39	
2	Los Angeles	34.249	7	360	0.94	22
	Sepulveda VA Hospital	118.475		Up	0.48	
	[VA] Ground			270	0.74	
3	Los Angeles	34.175	8	360	0.76	
	5805 Sepulveda Blvd.	118.465		Up	0.50	**
	[CODE] Roof (9)			270	0.64	
4	Los Angeles	34.156	8	120	0.37	24
	16000 Ventura Blvd.	118.480		Up	0.37	
	[CODE] Roof (13)			030	0.41	
5	Los Angeles	34.157	8	360	0.61	24
	15250 Ventura Blvd.	118.476		Up	0.43	
	[CODE] Roof (13)			270	0.27	
6	Jensen Filter Plant	34.312	12	022	0.40	23
	Administration Building	118.496		Up	0.40	
	[MWD] Basement			292	0.62	
6	Jensen Filter Plant	34.313	12	022	0.56	22
	Generator Building	118.498		Up	0.52	
	[MWD] Ground			292	0.98	
6	Jensen Filter Plant	34.309	12	022	0.65	23
	Reservoir Roof	118.499		Up	0.51	
	[MWD]			292	0.84	
7	Sepulveda Canyon	34.097	14	166	0.26	25
	Spillway Building	118.475		Up	0.16	
	[MWD] Ground			076	0.43	
8	Topanga	34.084	15	360	0.34	27
	Fire Station	118.599		Up	0.19	
	[USGS] Ground			270	0.21	
9	Santa Susana	34.232	16	325	0.32	
	ETEC, Bldg. 026	118.710		Up	0.27	*
	[DOE] Ground			235	---	
9	Santa Susana	34.230	16	090	0.24	26
	ETEC, Bldg. 462	118.712		Up	0.23	
	[DOE] 1st Floor			360	0.34	
9	Santa Susana	34.230	16	090	0.41	26
	ETEC, Bldg. 462	118.712		Up	0.40	
	[DOE] 6th Floor			360	0.50	
9	Santa Susana	34.230	16	090	0.41	
	ETEC, Bldg. 463	118.713		Up	0.66	*
	[DOE] Roof			360	0.76	

USGS STRONG-MOTION DATA FROM THE Ms=6.6 NORTHRIDGE, CALIFORNIA EARTHQUAKE OF JANUARY 17, 1994 (Continued)

MAP INDEX NO.	STATION LOCATION [OWNER]	COORDINATES (Lat. ° N Long. ° W)	EPICENTRAL DISTANCE (km)	ACCELERATION DIRECTION (Degrees)	ACCELERATION MAXIMUM (g)	RECORD PAGE NO.
9	Santa Susana	34.231	16	090	0.29	25
	ETEC, Freefield	118.713		Up	0.16	
	[DOE] Ground			360	0.23	
10	Los Angeles	34.063	18	285	0.16	27
	Brentwood VA Hospital	118.463		Up	0.14	
	[VA] Ground			195	0.18	
11	Los Angeles	34.058	19	070	0.14	32
	10920 Wilshire Blvd.	118.443		Up	0.24	
	[CODE] 19th Level			340	0.17	
12	Los Angeles	34.060	19	252	0.40	28
	10751 Wilshire Blvd.	118.438		Up	0.39	
	[CODE] Roof (12)			162	0.30	
13	Los Angeles	34.061	19	160	0.43	28
	10660 Wilshire Blvd.	118.434		Up	0.51	
	[CODE] Roof (19)			070	1.00	
14	Los Angeles	34.053	19			
	Wadsworth VA Hospital	118.452				
	(VA)					
	Structural Array					29
	Ch. 1 - 6th Floor, North			235	0.56	
	2 - 6th Floor, North-center			235	0.44	
	3 - 6th Floor, Center			235	0.46	
	4 - 6th Floor, Center			055	0.46	
	5 - 6th Floor, South			055	0.46	
	6 - 6th Floor, South			335	0.49	
	7 - Basement, North-center			325	0.21	
	8 - Basement, North-center			235	0.22	
	9 - Basement, North-center			Down	0.09	
14	Los Angeles	34.054	19	325	0.26	31
	Wadsworth VA Hospital	118.453		Up	0.17	
	[USGS] North Ground Site			235	0.26	
14	Los Angeles	34.050	19	325	0.39	31
	Wadsworth VA Hospital	118.448		Up	0.14	
	[USGS] South Ground Site			235	0.30	
15	Los Angeles	34.044	20	226	0.27	32
	12121 Wilshire Blvd.	118.467		Up	0.37	
	[CODE] Roof (15)			136	0.32	
16	Los Angeles	34.059	20	320	0.31	
	2029 Century Park East	118.413		Up	0.46	**
	[CODE] 43rd Floor			230	0.32	
17	Malibu Canyon	34.078	21	360	0.20	33
	Monte Nido Fire Station	118.693		Up	0.13	
	[USGS] Ground			270	0.17	

USGS STRONG-MOTION DATA FROM THE Ms=6.6 NORTHRIDGE, CALIFORNIA EARTHQUAKE OF JANUARY 17, 1994 (Continued)

MAP INDEX NO.	STATION LOCATION [OWNER]	COORDINATES (Lat. ° N Long. ° W)	EPICENTRAL DISTANCE (km)	ACCELERATION		RECORD PAGE NO.
				DIRECTION (Degrees)	MAXIMUM (g)	
18	**Los Angeles**	34.057	21	330	0.43	33
	2121 Ave. of the Stars	118.414		Up	0.63	
	[CODE] Roof (36)			240	0.37	
19	**Los Angeles**	34.040	21	235	0.44	34
	1955 1/2 Purdue Ave.	118.445		Up	0.16	
	[USGS] Basement			145	0.39	
19	**Los Angeles**	34.040	21	235	0.50	34
	1955 1/2 Purdue Ave.	118.445		Up	0.48	
	[USGS] 1st Level			145	0.49	
19	**Los Angeles**	34.040	21	235	0.63	35
	1955 1/2 Purdue Ave.	118.445		Up	0.46	
	[USGS] 3rd Level			145	0.46	
20	**Los Angeles**	34.071	22	335	0.55	36
	444 S. San Vicente	118.374		Up	0.31	
	[CODE] Roof (12)			245	0.64	
21	**Los Angeles**	34.106	22	360	0.36	36
	2005 N. Highland Ave.	118.336		Up	0.21	
	[CODE] Roof (8)			270	0.42	
22	**Los Angeles**	34.118	24	360	0.18	35
	Griffith Observatory	118.299		Up	0.15	
	[USGS] Ground			270	0.29	
23	**Los Angeles**	34.063	25	180	0.42	37
	4929 Wilshire Blvd.	118.337		Up	0.31	
	[CODE] Roof (11)			090	0.34	
24	**Los Angeles**	34.098	26	090	0.84	37
	1526 N. Edgemont St.	118.294		Up	0.27	
	[CODE] Roof (8)			360	0.78	
25	**Los Angeles**	34.060	28	360	0.12	38
	695 S. Vermont	118.290		Up	0.19	
	[CODE] 18th Floor			270	0.11	
26	**Los Angeles**	34.063	29	028	0.24	38
	600 S. Commonwealth	118.284		Up	0.22	
	[CODE] 19th Floor			298	0.17	
27	**Los Angeles**	34.052	31	298	0.13	41
	1100 Wilshire Blvd.	118.263		Up	0.09	
	[USGS] Bsmt 3 NE			208	0.15	
27	**Los Angeles**	34.052	31	298	0.14	41
	1100 Wilshire Blvd.	118.263		Up	0.07	
	[USGS] Bsmt 3 SE			208	0.10	
27	**Los Angeles**	34.052	31	298	0.11	40
	1100 Wilshire Blvd.	118.263		Up	0.06	
	[USGS] Bsmt 4 NW			208	0.12	

USGS STRONG-MOTION DATA FROM THE Ms=6.6 NORTHRIDGE, CALIFORNIA EARTHQUAKE OF JANUARY 17, 1994 (Continued)

MAP INDEX NO.	STATION LOCATION [OWNER]	COORDINATES (Lat. ° N Long. ° W)	EPICENTRAL DISTANCE (km)	ACCELERATION DIRECTION (Degrees)	ACCELERATION MAXIMUM (g)	RECORD PAGE NO.
27	Los Angeles	34.052	31			
	1100 Wilshire Blvd.	118.263				
	[USGS]					
	Structural Array					42
	Ch. 1 - 12th Floor North			298	0.16	
	2 - 12th Floor North			208	0.22	
	3 - 12th Floor South			208	0.16	
	4 - 13th Floor North			298	0.16	
	5 - 13th Floor North			208	0.28	
	6 - 13th Floor South			208	0.16	
	7 - 32nd Floor North			298	0.14	
	8 - 32nd Floor North			208	0.35	
	9 - 32nd Floor South			208	0.16	
	10 - Ground Floor North			298	0.18	
	11 - Ground Floor North			208	0.11	
	12 - Ground Floor South			208	0.19	
28	Los Angeles	34.067	31	348	0.13	39
	1111 Sunset Blvd.	118.248		Up	0.06	
	[MWD] Basement			258	0.13	
28	Los Angeles	34.067	31	348	0.17	39
	1111 Sunset Blvd.	118.248		Up	0.09	
	[MWD] 4th Floor			258	0.18	
28	Los Angeles	34.067	31	348	0.23	40
	1111 Sunset Blvd.	118.248		Up	0.16	
	[MWD] Roof (8)			258	0.23	
29	Los Angeles	34.053	32	083	0.11	45
	333 South Hope	118.252		Up	0.18	
	[CODE] 55th Floor			353	0.11	
30	Los Angeles	34.049	32	045	0.19	44
	500 S. Grand Ave.	118.252		Up	0.17	
	[CODE] 25th Level			315	0.17	
31	Los Angeles	34.050	32	045	0.15	44
	520 S.Grand Ave.	118.252		Up	0.13	
	[CODE] 11th Level			315	0.24	
32	Los Angeles	34.039	32	307	0.13	45
	1150 South Hill	118.259		Up	0.15	
	[CODE] 10th Floor			217	0.08	
33	Los Angeles	33.946	32	270	0.14	46
	6101 Century Blvd.	118.391		Up	0.10	
	[CODE] 15th Level			180	0.18	
34	Los Angeles	33.945	33	090	0.16	46
	5250 Century Blvd.	118.372		Up	0.22	
	[CODE] Roof (8)			360	0.15	

USGS STRONG-MOTION DATA FROM THE Ms=6.6 NORTHRIDGE, CALIFORNIA EARTHQUAKE OF JANUARY 17, 1994 (Continued)

MAP INDEX NO.	STATION LOCATION [OWNER]	COORDINATES (Lat. ° N Long. ° W)	EPICENTRAL DISTANCE (km)	ACCELERATION		RECORD PAGE NO.
				DIRECTION (Degrees)	MAXIMUM (g)	
35	Burbank	34.152	20	360	0.56	47
	3601 W. Olive Ave	118.337		Up	0.81	
	[CODE] Roof (9)			270	0.52	
36	Lawndale	33.895	38	360	0.18	49
	15000 Aviation Blvd.	118.377		Up	0.09	
	[USGS] Ground			270	0.13	
37	Alhambra	34.085	38			
	900 South Fremont Ave.	118.149				
	[USGS]					
	Structural Array					50
	Ch. 1 - 12th Floor Center			360	0.11	
	2 - 12th Floor Center			090	0.16	
	3 - 12th Floor North end			090	0.13	
	4 - 6th Floor Center			090	0.24	
	5 - 6th Floor Center			360	0.15	
	6 - 6th Floor North end			090	0.20	
	7 - 2nd Floor Center			090	0.60	
	8 - 2nd Floor Center			360	0.39	
	9 - 2nd Floor North end			090	0.40	
	10 - Basement Center			360	0.13	
	11 - Basement Center			Up	0.10	
	12 - Basement Center			090	0.19	
38	Pasadena (Analog)	34.136	39	360	0.16	47
	535 S. Wilson Ave.	118.127		Up	0.10	
	[USGS] Ground			270	0.15	
38	Pasadena (Digital)	34.136	39	~~360~~ 180	0.19	48
	535 S. Wilson Ave.	118.127		Up	0.11	
	[USGS] Ground			270	0.15	
39	Los Angeles	33.996	42	360	0.27	49
	Bulk Mail Facility (Bell)	118.162		Up	0.09	
	[USGS] Ground			270	0.16	
40	Garvey Reservoir	34.050	43	114	0.16	52
	Crest	118.114		Up	0.08	
	[MWD]			024	0.18	
40	Garvey Reservoir	34.048	43	114	0.14	52
	Abutment Building	118.111		Up	0.07	
	[MWD] Ground			024	0.12	
41	Los Angeles	33.855	46	360	0.14	53
	19191 S. Vermont	118.291		Up	0.10	
	[CODE] Roof (11)			270	0.22	
42	Chantry Flat	34.196	48	~~290~~ 110	0.20	54
	Forest Station, Heliport	118.021		Up	0.12	
	[USGS] Ground			~~020~~ 200	0.26	

USGS STRONG-MOTION DATA FROM THE Ms=6.6 NORTHRIDGE, CALIFORNIA
EARTHQUAKE OF JANUARY 17, 1994 (Continued)

MAP INDEX NO.	STATION LOCATION [OWNER]	COORDINATES (Lat. ° N Long. ° W)	EPICENTRAL DISTANCE (km)	ACCELERATION		RECORD PAGE NO.
				DIRECTION (Degrees)	MAXIMUM (g)	
43	Whittier Narrows Dam	34.020	49	~~028~~ 208	0.19	55
	Crest	118.053		Up	0.07	
	[ACOE]			~~118~~ 298	0.21	
43	Whittier Narrows Dam	34.031	49	~~360~~ 180	0.22	56
	Upstream (Baseyard)	118.054		Up	0.08	
	[ACOE]			~~090~~ 270	0.15	
	Leona Valley	34.620	51	120	0.05	57
	Fire Station	118.290		Up	0.06	
	[USGS] Ground			030	0.07	
45	Palos Verdes Reservoir	34.774	53	210	0.15	59
	Abutment Bldg.	118.321		Up	0.10	
	[MWD] Ground			120	0.12	
45	Palos Verdes Reservoir	33.772	53	210	0.12	59
	Crest	118.319		Up	0.07	
	[MWD]			120	0.15	
46	Whittier	33.977	53	180	0.15	57
	7215 Bright Ave., Basement	118.036		Up	0.07	
	[CODE/USGS]			090	0.12	
46	Whittier	33.977	53	180	0.30	58
	7215 Bright Ave., 5th Floor	118.036		Up	0.10	
	[CODE/USGS]			090	0.15	
46	Whittier	33.977	53	180	0.18	58
	7215 Bright Ave., 10th Floor	118.036		Up	0.12	
	[CODE/USGS]			090	0.24	
47	Norwalk	33.917	54	090	0.08	60
	12400 Imperial Highway	118.067		Up	0.06	
	[USGS] North Ground Site			360	0.08	
48	Norwalk	33.917	55	090	0.06	61
	12440 Imperial Highway	118.065		Up	0.06	
	[USGS] North Ground Site			360	0.08	
48	Norwalk	33.916	55	090	0.06	61
	12440 Imperial Highway	118.065		Up	0.04	
	[USGS] Basement			360	0.06	

USGS STRONG-MOTION DATA FROM THE Ms=6.6 NORTHRIDGE, CALIFORNIA
EARTHQUAKE OF JANUARY 17, 1994 (Continued)

MAP INDEX NO.	STATION LOCATION (OWNER)	COORDINATES (Lat. ° N Long. ° W)	EPICENTRAL DISTANCE (km)	ACCELERATION		RECORD PAGE NO.
				DIRECTION (Degrees)	MAXIMUM (g)	
48	Norwalk	33.916	55			
	12440 Imperial Highway	118.065				
	[USGS]					
	Structural Array					62
	Ch. 1 - 9th Level(Roof) Center			090	0.14	
	2 - 6th Level Center			090	0.11	
	3 - 3rd Level Center			090	0.08	
	4 - 2nd Level Center			090	0.07	
	5 - 1st Level(Bsmt) East end			180	0.06	
	6 - 6th Level West-center			180	0.11	
	7 - 1st Level(Bsmt) Center			Up	0.14	
	8 - 1st Level(Bsmt) Center			090	---	
	9 - 1st Level(Bsmt) Center			180	0.07	
	10 - Downhole (30') Center			Up	0.03	
	11 - Downhole (30') Center			090	---	
	12 - Downhole (30') Center			180	0.06	
48	Norwalk	33.916	55			
	12440 Imperial Highway	118.065				
	[USGS]					
	Structural Array					63
	Ch. 13 - 9th Level Roof East end			180	0.14	
	14 - 6th Level East end			180	0.09	
	15 - 3rd Level East end			180	0.05	
	16 - 2nd Level East end			180	0.06	
	17 - 9th Level Roof Bldg ctr			180	0.18	
	18 - 6th Level Bldg Ctr			180	0.13	
	19 - 3rd Level Bldg Ctr			180	0.09	
	20 - 2nd Level Bldg Ctr			180	0.08	
	21 - 9th Level Roof West end			180	0.12	
	22 - 6th Level West end			180	0.08	
	23 - 3rd Level West end			180	0.06	
	24 - 2nd Level West end			180	0.07	
49	Morris Dam	34.173	61	246	0.04	60
	Left abutment	117.879		Up	0.03	
	[MWD]			156	0.03	
	Littlerock	34.52	61	300	0.13	65
	Post Office	117.99		Up	0.08	
	[USGS] Ground			210	0.18	
51	Long Beach VA Hospital	33.778	62	360	0.07	66
	Basement	118.118		Up	0.04	
	[VA]			270	0.05	
51	Long Beach VA Hospital	33.778	62	360	0.15	67
	6th Floor	118.118		Up	0.06	
	[VA]			270	0.11	
51	Long Beach VA Hospital	33.778	62	360	0.20	67
	11th Floor	118.118		Up	0.08	
	[VA]			270	0.21	

USGS STRONG-MOTION DATA FROM THE Ms=6.6 NORTHRIDGE, CALIFORNIA
EARTHQUAKE OF JANUARY 17, 1994 (Continued)

MAP INDEX NO.	STATION LOCATION (OWNER)	COORDINATES (Lat. ° N Long. ° W)	EPICENTRAL DISTANCE (km)	ACCELERATION DIRECTION (Degrees)	ACCELERATION MAXIMUM (g)	RECORD PAGE NO.
51	Long Beach VA Hospital	33.777	62	360	0.07	66
	Ground Site	118.115		Up	0.03	
	[VA]			270	0.07	
52	Brea Dam	33.890	67	132	0.14	69
	Crest	117.925		Up	0.09	
	[ACOE]			042	0.23	
52	Brea Dam	33.890	67	132	0.08	68
	Left Abutment	117.924		Up	0.08	
	[ACOE]			042	0.10	
52	Brea Dam	33.889	67	132	0.19	68
	Downstream	117.926		Up	0.05	
	[ACOE]			042	0.12	
53	Orange County Reservoir	33.936	68	090	0.20	70
	Crest	117.884		Up	0.09	
	[MWD]			360	0.19	
53	Orange County Reservoir	33.935	68	090	0.11	70
	Abutment	117.883		Up	0.05	
	[MWD]			360	0.11	
	Valyermo Forest Station	34.44	68	300	0.08	65
	[USGS] Ground	117.85		Up	0.05	
				210	0.07	
55	Weymouth Filter Plant	34.114	71	017	0.05	71
	Ground Site	117.778		Up	0.04	
	[MWD]			287	0.05	
55	Weymouth Filter Plant	34.115	71	017	0.16	71
	Tank Top	117.779		Up	0.11	
	[MWD]			287	0.11	
	Paradise Springs Camp	34.40	71	120	0.06	
	[USGS] Ground	117.80		Up	0.03	*
				030	0.05	
57	Carbon Canyon Dam	33.914	72	131	0.11	73
	Crest	117.839		Up	0.08	
	[ACOE]			041	0.19	
57	Carbon Canyon Dam	33.913	72	131	0.11	72
	Left Abutment	117.837		Up	0.03	
	[ACOE]			041	0.10	
57	Carbon Canyon Dam	33.916	72	131	0.14	72
	Right Abutment	117.842		Up	0.06	
	[ACOE]			041	0.14	
58	Live Oak Reservoir	34.140	73	180	0.04	69
	Abutment	117.749		Up	0.01	
	[MWD]			090	0.03	

USGS STRONG-MOTION DATA FROM THE Ms=6.6 NORTHRIDGE, CALIFORNIA EARTHQUAKE OF JANUARY 17, 1994 (Continued)

MAP INDEX NO.	STATION LOCATION (OWNER)	COORDINATES (Lat. ° N Long. ° W)	EPICENTRAL DISTANCE (km)	ACCELERATION DIRECTION (Degrees)	ACCELERATION MAXIMUM (g)	RECORD PAGE NO.
59	Diemer Filter Plant	33.913	74	281	0.07	73
	Administration Building	117.819		Up	0.04	
	[MWD] Basement			191	0.12	
59	Diemer Filter Plant	33.911	74	281	0.06	74
	Reservoir Roof	117.817		Up	0.05	
	[MWD]			191	0.11	
60	Huntington Beach	33.697	74	360	0.12	76
	18401 Springdale	118.023		Up	0.02	
	[USGS] Ground			270	0.11	
61	Orange	33.789	76	360	0.16	
	200 S. Manchester Ave.	117.894		Up	0.16	*
	[CODE] Roof (9)			270	0.11	
62	Orange	33.787	76	360	0.04	
	333 City Boulevard West	117.894		Up	0.10	*
	[CODE] 22nd Level			270	0.06	
63	Orange	33.783	76	360	0.11	
	600 City Parkway West	117.896		Up	0.10	*
	[CODE] 11th Floor			270	0.14	
64	Orange	33.782	76	360	0.11	
	505 City Parkway West	117.896		Up	0.11	*
	[CODE] 11th Floor			270	0.08	
65	San Antonio Dam	34.156	80	090	0.05	76
	Downstream	117.675		Up	0.03	
	[ACOE]			360	0.09	
66	Santa Ana, 400 Civic Cntr Dr.	33.751	80	360	0.08	77
	Orange County Engineering Bl.	117.870		Up	0.03	
	[USGS] Basement			270	0.06	
67	Costa Mesa Fire Station #4	33.658	83	360	0.08	77
	2300 Placentia Ave.	117.931		Up	0.04	
	[USGS] Ground			270	0.05	
68	Wrightwood	34.360	85	360	0.08	78
	Post Office	117.629		Up	0.03	
	[USGS] Ground			270	0.07	
69	Costa Mesa	33.677	86	360	0.09	78
	John Wayne Airport	117.869		Up	0.03	
	[USGS] Ground			270	0.07	
70	Irvine	33.682	87	360	0.06	74
	2603 Main Street	117.842		Up	0.03	
	[CODE] Ground			270	0.11	
70	Irvine	33.682	87	360	0.11	75
	2603 Main Street	117.842		Up	0.07	
	[CODE] 7th Level			270	0.11	

USGS STRONG-MOTION DATA FROM THE Ms=6.6 NORTHRIDGE, CALIFORNIA EARTHQUAKE OF JANUARY 17, 1994 (Continued)

MAP INDEX NO.	STATION LOCATION [OWNER]	COORDINATES (Lat. ° N Long. ° W)	EPICENTRAL DISTANCE (km)	ACCELERATION		RECORD PAGE NO.
				DIRECTION (Degrees)	MAXIMUM (g)	
70	Irvine	33.682	87	360	0.10	75
	2603 Main Street	117.842		Up	0.08	
	[CODE] 13th Level			270	0.09	
71	Irvine	33.682	87	360	0.11	
	2601 Main Street	117.842		Up	0.07	*
	[CODE] 13th Level			270	0.11	
72	Irvine	33.656	88	060	0.07	79
	19900 MacArthur Blvd.	117.859		Up	0.02	
	[USGS] Basement			330	0.04	
72	Irvine	33.656	88			
	19900 MacArthur Blvd.	117.859				
	[USGS]					
	Structural Array					80
	Ch. 1 - Roof NE corner			060	0.18	
	2 - Roof SW corner			060	0.17	
	3 - 7th Floor NE			060	0.13	
	4 - 7th Floor SW			060	0.13	
	5 - 1st Floor South side			060	0.07	
	6 - Roof, SW corner			330	0.11	
	7 - 7th Floor, SW			330	0.12	
	8 - 1st Floor West side			330	0.07	
	9 - 1st Floor South side			330	0.06	
	10 - 7th Floor SW corner			Down	0.14	
	11 - 1st Floor West side			Down	0.01	
	12 - 1st Floor South side			Down	0.03	
73	Newport Beach	33.618	90			
	800-840 Newport Center Drive	117.878				
	[USGS]					
	Structural Array					82
	Ch. 1 - Tower 2 Level 1 Center			020	0.06	
	2 - Tower 2 Level 1 Center			Up	0.02	
	3 - Tower 2 Level 1 Center			110	0.04	
	4 - Tower 2 Level 2 West			110	0.09	
	5 - Middle Building Level 2			020	0.11	
	6 - Middle Building Level 2			110	0.10	
	7 - Tower 2, Level 9 South			110	0.07	
	8 - Tower 2, Level 10 Center			020	0.05	
	9 - Tower 2, Level 10 Center			110	0.07	
	10 - Tower 1, Level 9 East			110	0.06	
	11 - Tower 1, Level 10 Ctr			020	0.06	
	12 - Tower 1, Level 10 Ctr			110	0.04	
74	Prado Dam	33.890	90	090	0.09	84
	Crest	117.641		Up	0.07	
	[ACOE]			360	0.10	
74	Prado Dam	33.888	90	090	0.20	79
	Downstream	117.640		Up	0.06	
	[ACOE]			360	0.18	

USGS STRONG-MOTION DATA FROM THE Ms=6.6 NORTHRIDGE, CALIFORNIA EARTHQUAKE OF JANUARY 17, 1994 (Continued)

MAP INDEX NO.	STATION LOCATION (OWNER)	COORDINATES (Lat. ° N Long. ° W)	EPICENTRAL DISTANCE (km)	ACCELERATION		RECORD PAGE NO.
				DIRECTION (Degrees)	MAXIMUM (g)	
74	Prado Dam	33.890	90	090	0.06	84
	Left Abutment	117.637		Up	0.04	
	(ACOE)			360	0.14	
75	San Joaquin Reservoir	33.620	92	087	0.04	85
	Crest	117.842		Up	0.02	
	(MWD)			357	0.04	
75	San Joaquin Reservoir	33.620	92	087	0.12	85
	Left Abutment	117.844		Up	0.07	
	(MWD)			357	0.14	
	Newport Beach	33.600	92	360	0.03	
	800 Marguerite	117.866		Up	0.02	*
	(USGS) Ground			270	0.05	
	Lytle Creek	34.251	96	360	0.08	86
	Mt. Lakes Resort	117.490		Up	0.03	
	(USGS) Ground			270	0.07	
	San Bernardino Array	34.235	104	360	0.05	89
	Devore Water Department	117.407		Up	0.02	
	(USGS) Ground			270	0.07	
	Riverside	33.968	104	166	0.05	86
	Santa Ana River Bridge	117.447		Up	0.03	
	(USGS/MWD) N. Abutment			076	0.04	
	Riverside	33.968	104			
	Santa Ana River Bridge	117.447				
	(USGS/MWD)					
	Structural Array					87
	Ch. 1 - North abutment			346	0.04	
	2 - North abutment			Down	0.02	
	3 - North abutment			076	0.03	
	4 - Pier 7-8, mid-span			346	0.16	
	5 - Pier 7-8, mid-span			Down	0.12	
	6 - Pier 7-8, mid-span			076	0.11	
	7 - Pier 8, below bearing			346	0.09	
	8 - Pier 8, below bearing			Down	0.02	
	9 - Pier 8, below bearing			076	0.03	
	10 - Pier 8 above bearing			346	0.11	
	11 - Pier 8 above bearing			Down	0.02	
	12 - Pier 8 above bearing			076	0.17	
	Lake Mathews Dam	33.852	108	252	0.03	89
	Dike Toe	117.451		Up	0.03	
	(MWD)			162	0.05	
	San Bernardino Array	34.134	108	360	0.03	
	Rialto Fire Station	117.368		Up	0.03	*
	(USGS) Ground			270	0.03	

USGS STRONG-MOTION DATA FROM THE Ms=6.6 NORTHRIDGE, CALIFORNIA EARTHQUAKE OF JANUARY 17, 1994 (Continued)

MAP INDEX NO.	STATION LOCATION [OWNER]	COORDINATES (Lat. ° N Long. ° W)	EPICENTRAL DISTANCE (km)	ACCELERATION		RECORD PAGE NO.
				DIRECTION (Degrees)	MAXIMUM (g)	
	San Bernardino Array	34.086	114	360	0.05	90
	San Bernardino Valley College	117.309		Up	0.03	
	[USGS] Ground			270	0.07	
	San Bernardino Array	34.183	114	360	0.05	90
	North "F" Street	117.295		Up	0.02	
	[USGS] Ground			270	0.06	
	San Bernardino	34.106	116	090	0.04	91
	385 N. Arrowhead Ave.	117.287		Up	0.02	
	[USGS] Ground Level			360	0.05	
	San Bernardino	34.106	116			
	385 N. Arrowhead Ave.	117.287				
	[USGS]					
	Structural Array					92
	Ch. 1 - 2nd Floor NW			360	0.07	
	2 - 2nd Floor NE			090	0.07	
	3 - 2nd Floor NE			360	0.08	
	4 - 2nd Floor SW			090	0.07	
	5 - 4th Floor SW			090	0.14	
	6 - 4th Floor NW			360	0.11	
	7 - Roof (6th) NE			090	0.15	
	8 - Roof (6th) NW			360	0.25	
	9 - Roof (6th) SW			090	0.21	
	10 - Roof (6th) NE			360	0.21	
	11 - 4th Floor NE			090	0.10	
	12 - 4th Floor NE			360	0.15	
	San Bernardino	34.106	116	360	0.04	91
	385 N. Arrowhead Ave.	117.287		Up	0.02	
	[USGS] East Ground Site			270	0.04	
	Mills Filter Plant	33.920	117	360	0.02	
	[MWD] Ground	117.320		Up	0.02	*
				270	0.02	
	Loma Linda University	34.050	119	360	0.04	
	Medical Center	117.263		Up	0.02	*
	[USGS] Ground			270	0.04	
	Loma Linda VA Hospital	34.051	120	360	0.05	94
	North Ground Site	117.248		Up	0.02	
	[VA]			270	0.05	
	Loma Linda VA Hospital	34.049	120	360	0.04	94
	South Ground Site	117.250		Up	0.03	
	[VA]			270	0.05	

USGS STRONG-MOTION DATA FROM THE Ms=6.6 NORTHRIDGE, CALIFORNIA
EARTHQUAKE OF JANUARY 17, 1994 (Continued)

MAP INDEX NO.	STATION LOCATION [OWNER]	COORDINATES (Lat. ° N Long. ° W)	EPICENTRAL DISTANCE (km)	ACCELERATION		RECORD PAGE NO.
				DIRECTION (Degrees)	MAXIMUM (g)	
	Loma Linda VA Hospital	34.050	120			
	[VA]	117.249				
	Structural Array					95
	Ch. 1 - Ground Floor Center			Down	0.02	
	2 - Ground Floor Center			180	0.05	
	3 - Ground Floor Center			270	0.04	
	4 - 4th Floor Center			270	0.16	
	5 - Ground Floor North			270	0.05	
	6 - 4th Floor Center			180	0.10	
	7 - 4th Floor North			270	0.16	
	8 - Ground Floor South			180	0.03	
	9 - 4th Floor South			270	0.13	
	Maricopa Array #2	35.040	123	040	0.03	
	[CDWR] Ground	119.430		Up	0.01	*
				310	0.02	
	Reche Canyon	34.004	123	330	0.02	
	Olive Dell Ranch	117.223		Up	0.01	*
	[USGS] Ground			240	0.02	
	Maricopa Array #3	35.080	125	040	0.03	
	[CDWR] Ground	119.400		Up	0.02	*
				310	0.04	
	Maricopa Array #4	35.130	127	040	0.03	
	[CDWR] Ground	119.370		Up	0.01	*
				310	0.03	
	Buena Vista Pumping Plant	35.160	129	105	0.02	
	Basement	119.345		Up	0.01	*
	[CDWR]			015	0.02	
	Buena Vista Pumping Plant	35.160	129	105	0.02	
	Ground	119.345		Up	0.01	*
	[CDWR]			015	0.02	
	Buena Vista Pumping Plant	35.160	129	105	0.03	
	Freefield	119.345		Up	0.01	*
	[CDWR]			015	0.04	
	San Bernardino Array	34.080	132	360	0.02	
	Mill Creek Ranger Station	117.114		Up	0.02	*
	[USGS] Ground			270	0.03	
	Skinner Dam	33.580	153	178	0.01	100
	Left Abutment	117.070		Up	0.01	
	[MWD]			088	0.02	
	Skinner Dam	33.580	153	~~355~~ 174	0.03	99
	Finished Water Reservoir	117.070		Up	0.03	
	[MWD] Crest			~~085~~ 264	0.03	

USGS STRONG-MOTION DATA FROM THE Ms=6.6 NORTHRIDGE, CALIFORNIA EARTHQUAKE OF JANUARY 17, 1994 (Continued)

MAP INDEX NO.	STATION LOCATION [OWNER]	COORDINATES (Lat. ° N Long. ° W)	EPICENTRAL DISTANCE (km)	ACCELERATION DIRECTION (Degrees)	ACCELERATION MAXIMUM (g)	RECORD PAGE NO.
	Skinner Dam - Toe [MWD]	33.580 117.070	153			
	Structural Array					97
	Ch. 1 - Center crest			180	0.05	
	2 - Center crest			Up	0.02	
	3 - Center crest			270	0.08	
	4 - Left crest			180	0.05	
	5 - Left crest			270	0.05	
	6 - Left slope			270	0.04	
	7 - Center slope			180	0.03	
	8 - Center slope			Up	0.02	
	9 - Center slope			270	0.04	
	10 - Center toe			180	0.02	
	11 - Center toe			Up	0.02	
	12 - Center toe			270	0.03	

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ACOE - U.S. Army Corps of Engineers
CDWR - Calif. Dept. of Water Resources
CODE - Building Owner
DOE - U.S. Dept. of Energy
MWD - Metropolitan Water District of So. Calif.
USGS - U.S. Geological Survey
VA - U.S. Dept. of Veterans Affairs

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