UNITED STATES NUCLEAR REGULATORY COMMISSION

POLICY ISSUE
(Information)

March 23, 1994 SECY-94-077

FOR: The Commissioners

FROM: James M. Taylor
Executive Director for Operations

SUBJECT: MAGNITUDE 6.7 NORTHRIDGE EARTHQUAKE OF JANUARY 17, 1994

PURPOSE:

To inform the Commission of the details of the Magnitude 6.7 Northridge Earthquake of January 17, 1994.

DISCUSSION:

On Monday, January 17, 1994, at 4:31 a.m., local time, a destructive earthquake with a Richter magnitude of 6.7 occurred in the Los Angeles Basin beneath the suburban town of Northridge in the San Fernando Valley. Significant damage was caused up to 64 kilometers (40 miles) from the epicenter. Numerous aftershocks have been recorded, several of magnitude 5 and greater. These aftershocks are continuing and are expected to continue for several months.

In an area where approximately 12 million people reside, sixty-one deaths, more than 8,000 injuries, and more than $15 billion dollars worth of damage have been attributed to the earthquake and several of the larger aftershocks. This is a relatively moderate-sized earthquake by California standards; however, some of the highest vertical accelerations (up to 1.2g) ever recorded were recorded at several seismograph stations (Figure 1) located in the area. Analysis of the ground motion records of the main shock and aftershocks, some of which are still being gathered, is underway and will be for some time in the future.

NOTE: TO BE MADE PUBLICLY AVAILABLE IN 10 WORKING DAYS FROM THE DATE OF THIS PAPER

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The causative fault of this seismicity was unknown to most, however, oil companies that had prospected in the area had identified it on geophysical records. A map of faults in the Los Angeles region is shown in Figure 2. Based on the preliminary analysis of some of the seismograms, the fault rupture causing the earthquake originated at a depth of 14 kilometers (8.7 miles) and propagated laterally and upward to near ground surface. The causative fault is oriented east northeast - west southwest and dips to the southwest at an angle of about 45 degrees. The sense of displacement on the fault is predominantly reverse, meaning that the block of landmass overlying the fault moved up and to the north relative to the block of landmass below the fault. The high vertical ground motions experienced in the area around Northridge are attributed to that region being situated on top of the overriding block. The causative fault most likely did not break the ground surface, but caused uplift at the surface and folding in the shallow subsurface. The U.S. Geological Survey (USGS), the California Division of Mines and Geology, several universities and other organizations are conducting investigations in the area.

The Northridge earthquake is similar in many ways to the 1971, magnitude 6.6, San Fernando earthquake, which also caused high vertical ground accelerations and was characterized by reverse faulting. The San Fernando earthquake differed in that the causative fault dipped to the north, and the block of rock atop the fault was thrust southward and upward, breaking ground surface, and raising the San Gabriel Mountains about 2 meters (6 feet). The 1987 Whittier Narrows earthquake had a similar origin.

There are more than 100 known thrust or reverse faults beneath the Los Angeles Basin, many of which are not exposed at ground surface, so earthquakes similar to the Northridge earthquake can be expected in the future. This earthquake reemphasizes the hazard to the Los Angeles Basin represented by seismically active faults at depths that do not displace ground surface during a destructive earthquake.

Ground motions were felt at the San Onofre Nuclear Power Plant site, located about 129 kilometers (80 miles) from the epicenter. The peak ground acceleration recorded there was 0.02g. The earthquake occurred 233 kilometers (145 miles) from the Diablo Canyon Nuclear Power plant site. Peak ground accelerations recorded there were 0.0022g (N-S), 0.0023g (E-W), and 0.0015g (Vert).

Site Visits

Site visits were performed by the Lawrence Livermore National Laboratory (LLNL); a consulting firm, EQE International (EQE); and a team composed of NRC, Department of Energy (DOE), Electric Power Research Institute (EPRI), and EQE staff.

LLNL Visit

Within a few hours of the earthquake, researchers from the LLNL traveled to the epicentral region to observe the effects of the earthquake. They studied how structures, systems, and components, similar to those found in nuclear power plants and DOE facilities, responded to the earthquake. Subsequent RES staff conversations with LLNL personnel indicated that the subject earthquake caused significant damage to facilities of interest to the NRC and that further investigations were warranted. Therefore, RES staff authorized LLNL to commence work on the project "Earthquake Investigations" and investigate the impact that this seismic event had on selected facilities to provide lessons learned that can have application to nuclear power plants. Under RES sponsorship, LLNL staff have participated in several post-earthquake activities associated with major earthquakes. Examples include (1) the El Centro Steam Plant response to the 1979 Imperial Valley earthquake, (2) damage to heavy industrial facilities caused by the 1985 Mexico City, and the 1987 New Zealand, Bay of Plenty earthquakes, (3) damage in the San Francisco Bay area caused by the 1989 Loma Prieta earthquake, (4) damage in northern and southern California caused by the 1992 earthquakes near Landers, Big Bear and Petrolia, California.

EQE Visit

EQE, an earthquake engineering consulting firm, sends staff to areas affected by major earthquakes and documents the successes and failures of residential structures, commercial buildings, and industrial facilities. This activity, supported mainly by EQE's industrial clients, is documented in EQE reports and is used throughout the technical community.

Because of their close proximity to the epicentral region, staff from EQE were able to take aerial and close-up photographs of the damaged area before major cleanup began, thus capturing the destructive nature of this earthquake. EQE staff concluded, in general, that those structures and equipment that had been retrofitted after the 1971 earthquake or built to current Codes and Standards performed well.

NRC/DOE/EPRI/EQE Visit

Roger M. Kenneally, DE/RES, and Pei-Ying Chen, DE/NRR, were part of a team (NRC, DOE, LLNL, BNL, EPRI, and EQE) that visited sites (February 7-9, 1994) damaged by the subject earthquake. In a briefing to the team on February 7, 1994, EQE staff showed slides and discussed the earthquake damage, providing comparisons of structure and equipment performance associated with this earthquake and the 1971 San Fernando earthquake. In general, the team members visited sites that contained structures, equipment, and piping similar to that found in nuclear power plants.

As discussed above (LLNL Visit), it was concluded that the earthquake caused significant damage to facilities of interest to the NRC and that NRC participation in further investigations was warranted. Although the NRC technical staff possesses the technical expertise to assess the damage, their access to affected areas or facilities would be difficult or impossible if they were not affiliated with an authorized investigatory team. Staff access to the damaged areas and facilities was obtained because they accompanied LLNL team members who possessed area access. In addition, facility access was obtained through EQE professional relationships.

Facility owners allowed the staff from the NRC, other government agencies, and the nuclear industry access to their facility to photograph the earthquake damage with the understanding that facility names and damage descriptions would not be made publicly available until the facility owners had approved said descriptions. Therefore, specific facility information (for example, name, location) is being withheld. Key findings are noted throughout the text. A report will be published by EPRI (co-sponsored by the NRC and DOE) that will discuss reconnaissance investigations. The estimated publication date is December 1994.

Damage to Residential Structures

There were widespread occurrences of typical earthquake damage including broken glass, fallen chimneys, and fallen unreinforced masonry walls. In addition, there were many severely damaged apartment buildings, especially those with parking garages at the first floor level because of a "soft first story" effect. Simplistically, this means that there is adequate shear resistance above the first floor; however, the first story is weakened because of the large cutouts provided for garages or other architectural reasons. Within the epicentral region, some low-rise houses moved off their foundations; many of the mobile homes fell from their jacks resulting in ruptured gas lines and fire damage.

Damage to Commercial Buildings

The Kaiser Permanente Medical Facility experienced collapse of several stories above the second floor. A major change in column size above the second floor (one-half the size of the columns between the first and second floor), poor beam-to-column joint details, and the proximity to the epicenter contributed to the collapse.

The California State University at Northridge parking structure collapsed (Figures 3 and 4). The proximity of the campus to the epicenter resulted in high vertical accelerations input into the base of the structure. Poor connection details (for instance, short development length of reinforcing steel between columns and floor slabs, short bearing seat at each beam end), high vertical accelerations, and seismic-induced horizontal movement contributed to the collapse of the structure.

Several other commercial buildings collapsed because of the "soft first story effect" described earlier.

Commercial buildings that did not collapse were not necessarily functional because of internal damage such as overturned bookcases, displaced ceiling tiles, or lack of power or water. Failure of sprinkler system piping caused excessive water damage.

Damage to Industrial Facilities

Successes and failures are noted below or depicted in Figures 5 through 12.

Well engineered structures and equipment that may have experienced ground motion far in excess of their design remained functional (Figure 5). Components made of brittle materials, such as ceramic insulators and cast iron components, received damage consistent with other earthquakes (Figure 6).

Two piping system failures were noted. A 3-inch valve body on a 4-inch piping line failed. Failure was possibly inertia induced (Figures 7 and 8). Also, there were reported breaks in the flange area of a 6-inch tee, and near the 3-inch end of a 6-inch to 3-inch reducer. The cause of these breaks is unknown.

There was a reported functional loss in a fiber optic cable (5 of 6 strands) due to the failure of the conduit.

There were no reported relay functional failures.

The lessons learned from this and other earthquakes, principally the need to upgrade anchorage, are being implemented. Butt welded kickplates were added to an air handler support in addition to through-the-floor bolting (Figure 9). Supports were added for hung valves (Figure 10), conduit, and tubing.

Damage to Bridges and Highways

Damage to highway overpasses and bridges occurs throughout the San Fernando Valley. Major damage and collapse were observed on Interstates 5, 10, and 210, and State Routes 14 and 118. Damage modes included shear failure of columns and bents (beams and columns), leading to settlement and collapse of the roadway deck above (Figures 13 and 14). Due to the proximity of the epicenter, the 118 Freeway bridge over San Fernando Mission and Gothic Streets experienced several cycles of relatively high vertical input acceleration. The bridge columns lost core confinement of the concrete, thereby losing their capacity to support large vertical loads.

Damage to Lifelines

Lifelines are defined as those facilities needed to service the population, that is, power systems, water and sewage systems, communications systems, and harbor and port facilities. Water systems are analogous to power systems in terms of collections, transmissions, and distribution. Water systems are more vulnerable than power systems because power systems are upgraded for economic reasons, whereas, water systems are more antiquated. Large water mains (40-inch and 60-inch), gas lines (6-inch and 22-inch), sewer lines and underground communications lines failed along Balboa Boulevard, north of Rinaldi Street (Figures 15 and 16). A compressional buckling of the ground surface as evidenced by a 2-foot length of the north portion of the sidewalk moving over the south portion (Figure 17) caused buckling and rupture of the lifelines. Several homes were burned as a result of the natural gas explosion. In contrast to the buried piping, a 5½-foot above-ground pipe a mile closer to the epicentral region appeared to have very little distress (Figure 18). Several days after the event, thousands of people were still without power, gas, and water.

Sources of Information

Several sources of information on the subject earthquake were used. These include (1) discussions with the staff of the U.S. Geological Survey (USGS), (2) publications issued by the California Division of Mines and Geology, Strong Motion Instrumentation Program (CSMIP), (3) the LLNL report, "Preliminary Observations of Damage from the January 17, 1994 Northridge Earthquake," dated January 27, 1994, sponsored in part through RES funding (The report, distributed to RES and NRR staff in a February 1, 1994, memorandum from Andrew J. Murphy, DE/RES, to Lawrence C. Shao, DE/RES, and M. Wayne Hodges, DE/NRR, dated February 1, 1994, contains proprietary material and is for internal NRC distribution only), (4) NRC staff participation in the NRC/DOE/EPRI/EQE team visit of February 7-9, 1994, (5) a briefing by EQE staff to the NRC/DOE/EPRI/EQE team on February 7, 1994, (EQE showed slides and discussed the earthquake damage, providing comparisons of structure and equipment performance associated with this earthquake and the 1971 San Fernando earthquake), and (6) the PG&E Reconnaissance Report on the Northridge earthquake of January 17, 1994.

Key Observations

Although this report has highlighted the failures associated with the subject earthquake, many structures, systems and components, even those close to the epicentral region, had little significant damage and could be occupied or were functional after the earthquake. In general, well engineered structures and equipment that may have experienced ground motion far in excess of their design remained functional. Components made of brittle materials, such as ceramic insulators and cast iron components, received damage consistent with other earthquakes.

The major surprises are the failure of a valve body and breaks in a piping system. The valve body failure may have been caused by a mode other than impact, possibly inertia. In the piping system there were breaks in the flange area of a 6-inch tee and near the 3-inch end of a 6-inch to 3-inch reducer. The causes of these failures are unknown. More investigation is needed to confirm the applicability of the observed failure information to nuclear power plant systems.

Summary

The very large earthquake that occurred in the Northridge, California area on January 17, 1994, once again appears to confirm the good performance of well-designed, well-detailed structures, systems, and components. The subject earthquake has produced a very large set of accelerograph records (Figure 1) that will be important in understanding the causes of any observed damage or lack of damage.

The staff, other government agencies, and the nuclear industry continue to study the effects of such earthquakes to improve our knowledge of the causes, frequency, and severity of earthquakes, seismic wave transmission, local site amplification, seismically caused soil failure, and the performance of structures and equipment similar to that utilized in nuclear facilities. Information such as that obtained from this earthquake has been very useful in dealing with both earth science and earthquake engineering issues. In the earth sciences area it has led to the development of probabilistic seismic hazard methods; ground motion studies to understand the propagation of strong earthquake motions, both over large distances and through a shallow soil column; and fault studies and data analyses to understand earthquake mechanisms and to compare the location and depth of different earthquakes against geological and tectonic information. In the earthquake engineering area it has helped in the resolution of issues such as Unresolved Safety Issue (USI) A-46, Verification of Seismic Adequacy of Equipment in Operating Plants and first-of-a-kind engineering (FOAKE) issues associated with advanced reactor designs.

A report co-sponsored by the NRC, DOE and EPRI will document the reconnaissance investigations. EPRI will publish the report; the estimated publication date is December 1994. Additional, independent staff evaluations may be warranted, in particular, the pump body and piping system failures.

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Enclosures:
Figures 1 through 18

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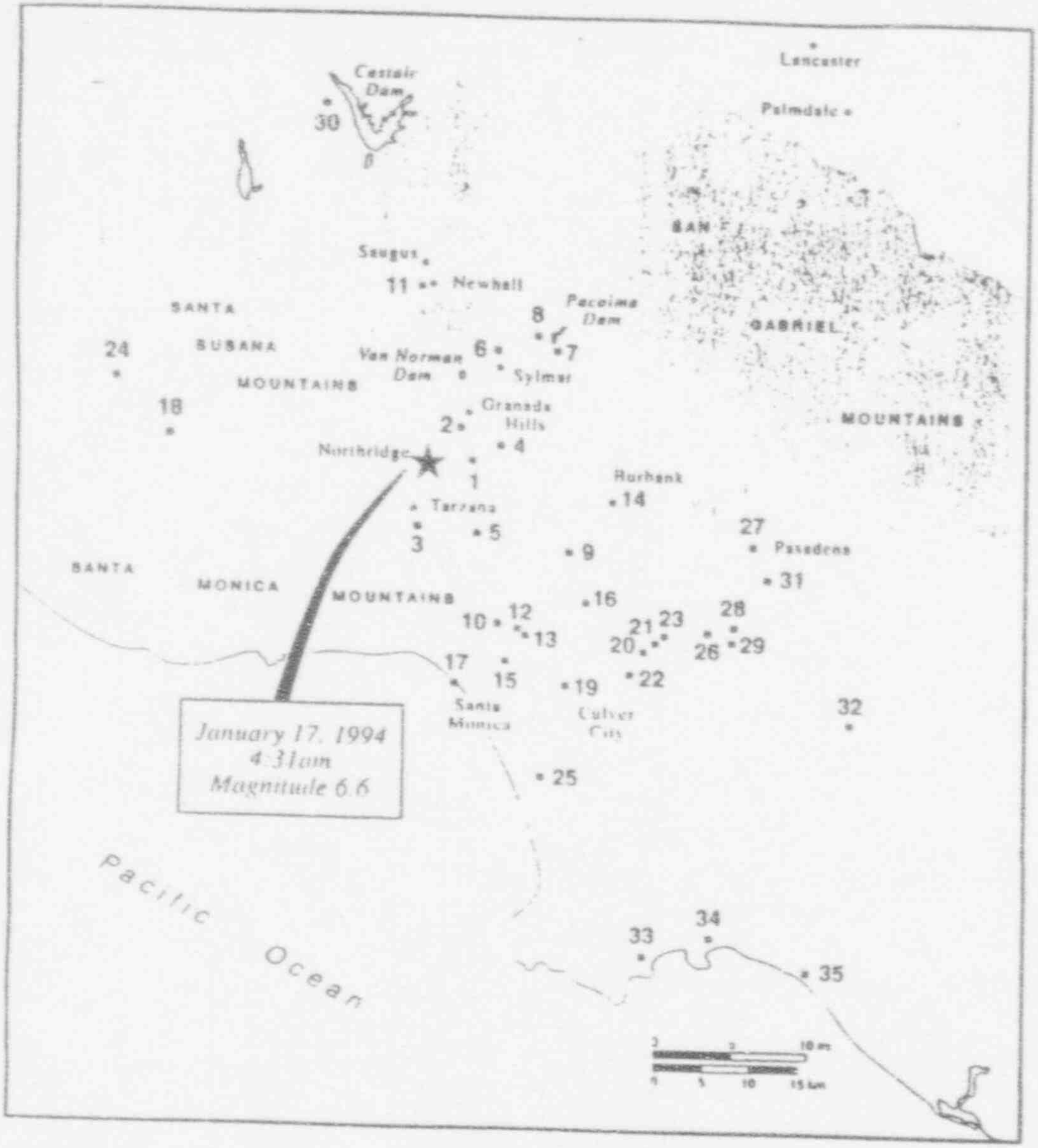


Stations Recording Ground Motion

1 Van Nuys - 7-story Hotel
Base = 0.47g (H), 0.30g(V)

2 Sepulveda VA Hospital
Ground level = 0.94g (H), 0.48g (V)

3 Tarzana - Cedar Hill Nursey
Free-field = 1.82g (H), 1.18g (V)

4 Arleta - Nordhoff Ave. Fire Station
Free-field = 0.35g (H), 0.59g (V)

5 Sherman Oaks - 13-story Commercial Bldg.
Base = 0.46g (H), 0.18g(V)

6 Sylmar - 3-story (Olive View) County Hospital
Free-field = 0.91g (H), 0.60g (V)
Base = 0.82g (H), 0.34g(V)

7 Pacoima - Kagel Canyon Fire Sta. #74
Free-field = 0.44g (H), 0.19g (V)

8 Pacoima Dam
Free-field = 0.44g (H), 0.20g (V)
Base = 0.54g (H), 0.43g(V)

9 North Hollywood - 20-story Hotel
Base = 0.33g (H), 0.15g (V)

10 Los Angeles - 7-story University Bldg.
Base = 0.29g (H), 0.25g(V)

11 Newhall - LA County Fire Station
Free-field = 0.63g (H), 0.62g (V)

12 Century City - LACC North
Free-field = 0.27g (H), 0.15g (V)

13 Los Angeles - 19-story Office Bldg.
Base = 0.32g (H), 0.13g(V)

14 Burbank - 10-story Residential Bldg.
Base = 0.30g (H), 0.13g(V)

Burbank - 6-story Commercial Bldg.
Base = 0.35g (H), 0.16g (V)

15 Los Angeles - 110/405 Interchange Bridge
Structure = 1.00g (H), 1.83g (V)

16 Los Angeles - Hollywood Storage Bldg.
Free-field = 0.41g (H), 0.19g (V)
Base = 0.29g (H), 0.11g(V)

17 Santa Monica - City Hall Grounds
Free-field = 0.93g (H), 0.25g (V)

18 Wood Ranch Dam
Structure = 0.39g (H), 0.18g (V)

19 Los Angeles - Baldwin Hills
Free-field = 0.24g (H), 0.10g (V)

20 Los Angeles - Pico and Sentous
Free-field = 0.19g (H), 0.07g (V)

21 Los Angeles - 52-story Office Bldg.
Base = 0.15g (H), 0.11g (V)

22 Los Angeles - 6-story Parking Structure
Base = 0.29g (H), 0.22g (V)

23 Los Angeles - 15-story Govt., LADWP Bldg.
Base = 0.21g (H), 0.07g (V)

24 Moorpark
Free-field = 0.30g (H), 0.15g (V)

25 El Segundo - 14-story Office Bldg.
Base = 0.13g (H), 0.04g (V)

26 Los Angeles - 7-story University Hospital
(Base isolated)
Free-field = 0.49g (H), 0.12g (V)
Base = 0.37g (H), 0.09g (V)

27 Pasadena - 6-story Office Bldg.
Base = 0.17g (H), 0.09g (V)

28 Los Angeles - 8-story CSULA Admin. Bldg.
Base = 0.17g (H), 0.06g (V)

29 Los Angeles - Fire Command Control Bldg.
(Base isolated)
Free-field = 0.32g (H), 0.13g (V)
Base = 0.22g (H), 0.11g (V)

30 Castaic - Old Ridge Route
Free-field = 0.59g (H), 0.25g (V)

31 San Marino - Southwestern Academy
Free-field = 0.16g (H), 0.09g (V)

32 Whittier - 8-story Hotel
Base = 0.19g (H), 0.10g (V)

33 Los Angeles - Vincent Thomas Bridge
Base = 0.26g (H), 0.08g (V)

34 Long Beach - 15-story Govt. Office Bldg.
City Hall ground
Free-field = 0.06g (H), 0.03g (V)
Base = 0.04g (H), 0.03g (V)

35 Seal Beach - 8-story Office Bldg.
(Base isolated)
Free-field = 0.09g (H), 0.04g (V)
Base = 0.08g (H), 0.03g (V)

Figure 1. Ground motion recordings from selected California Strong Motion Instrument Program stations (from PG&E Reconnaissance Report on the Northridge Earthquake of January 17, 1994, Figure 5).

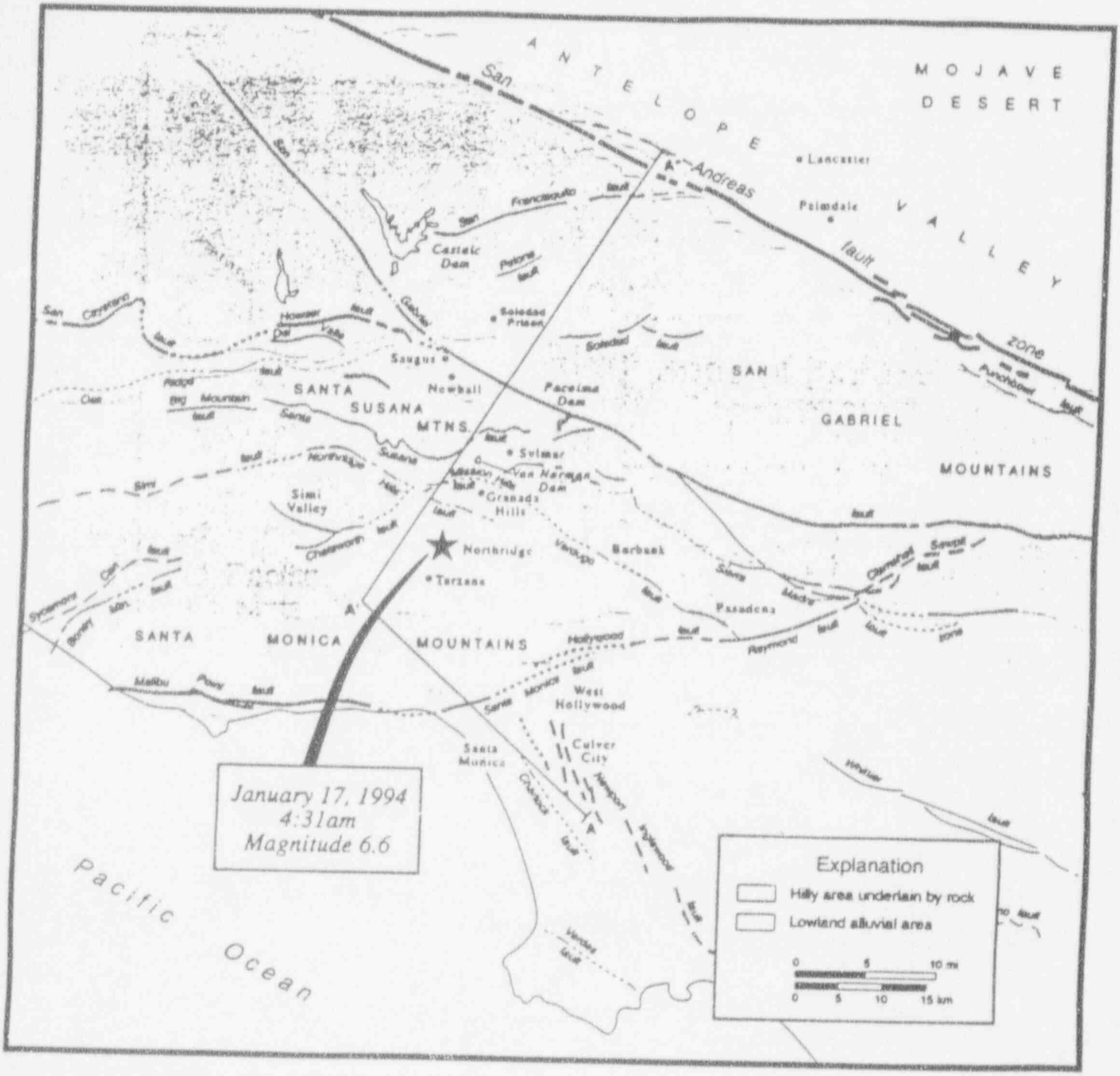
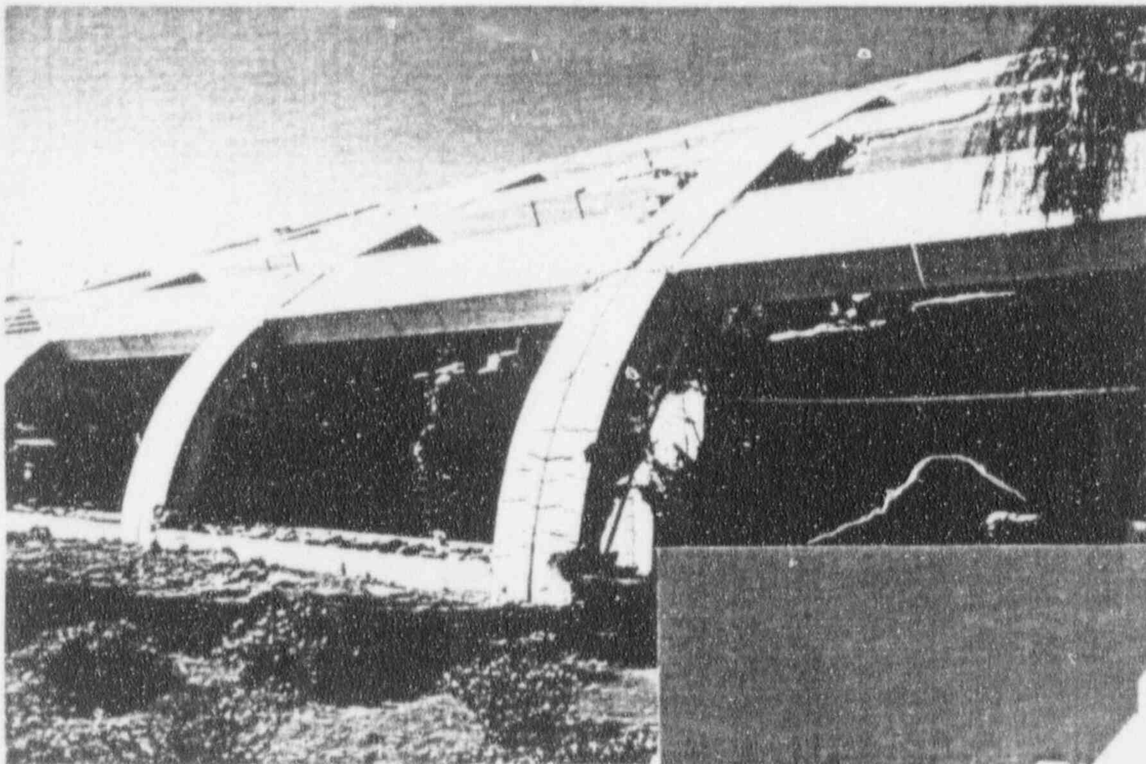
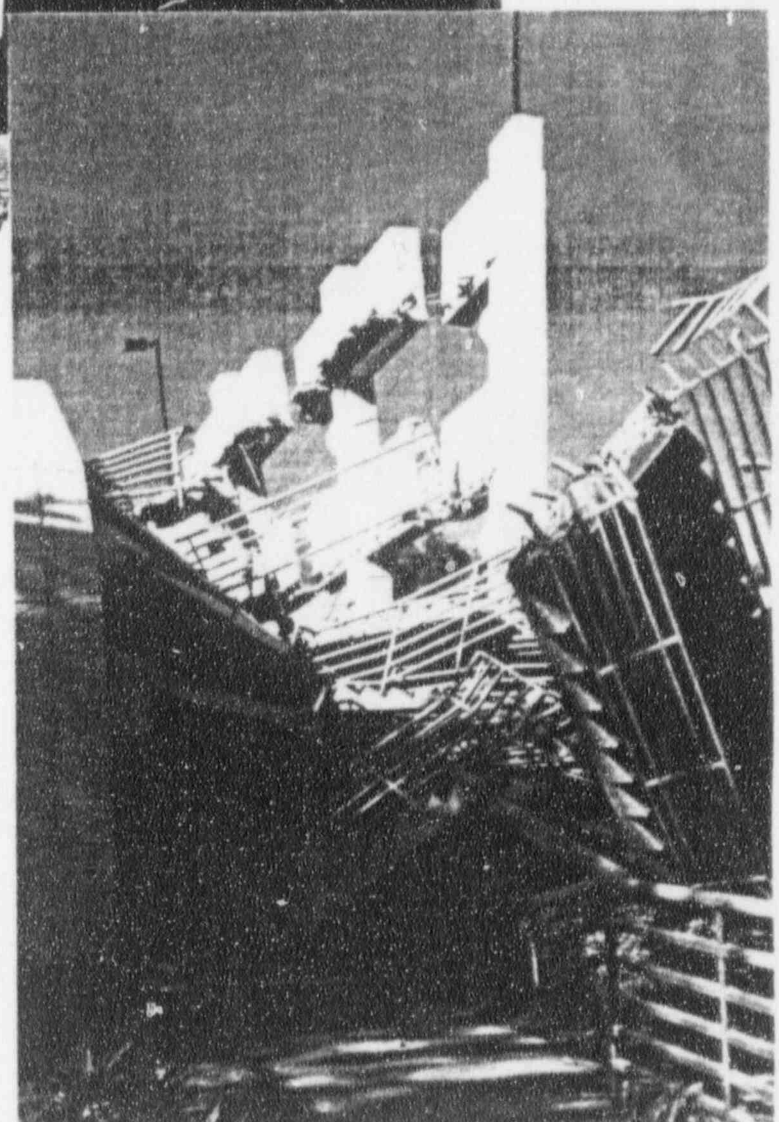
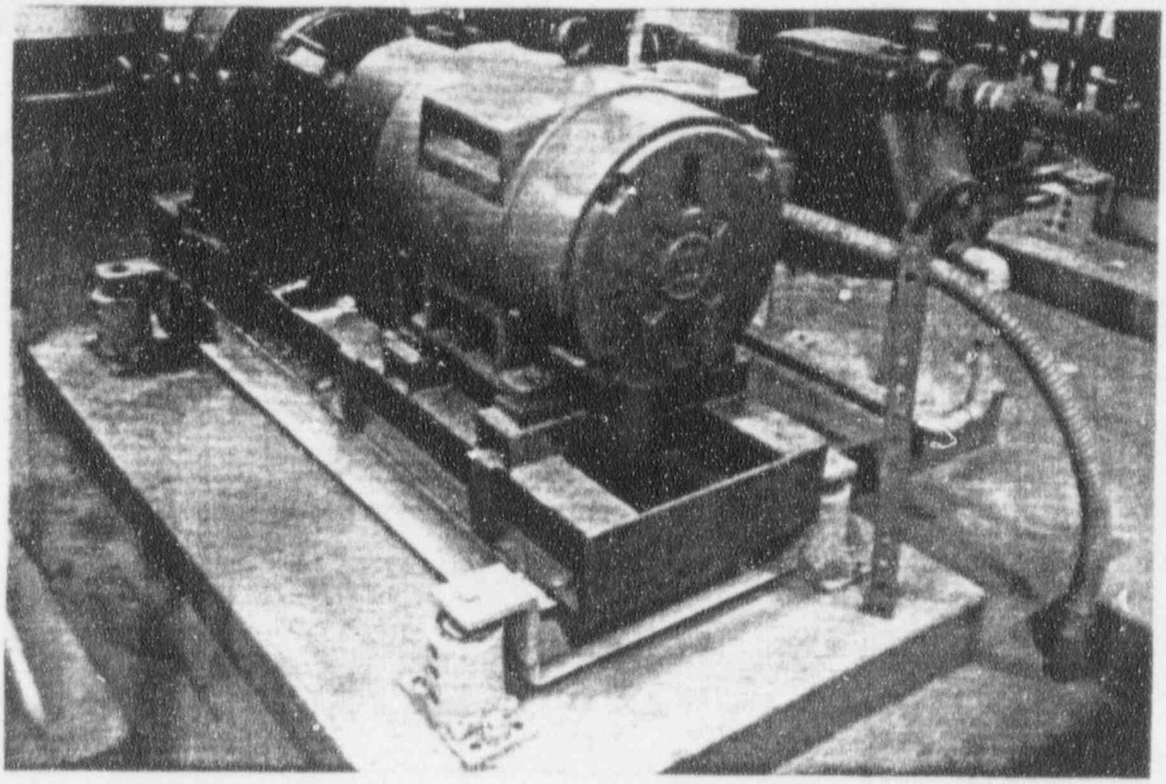


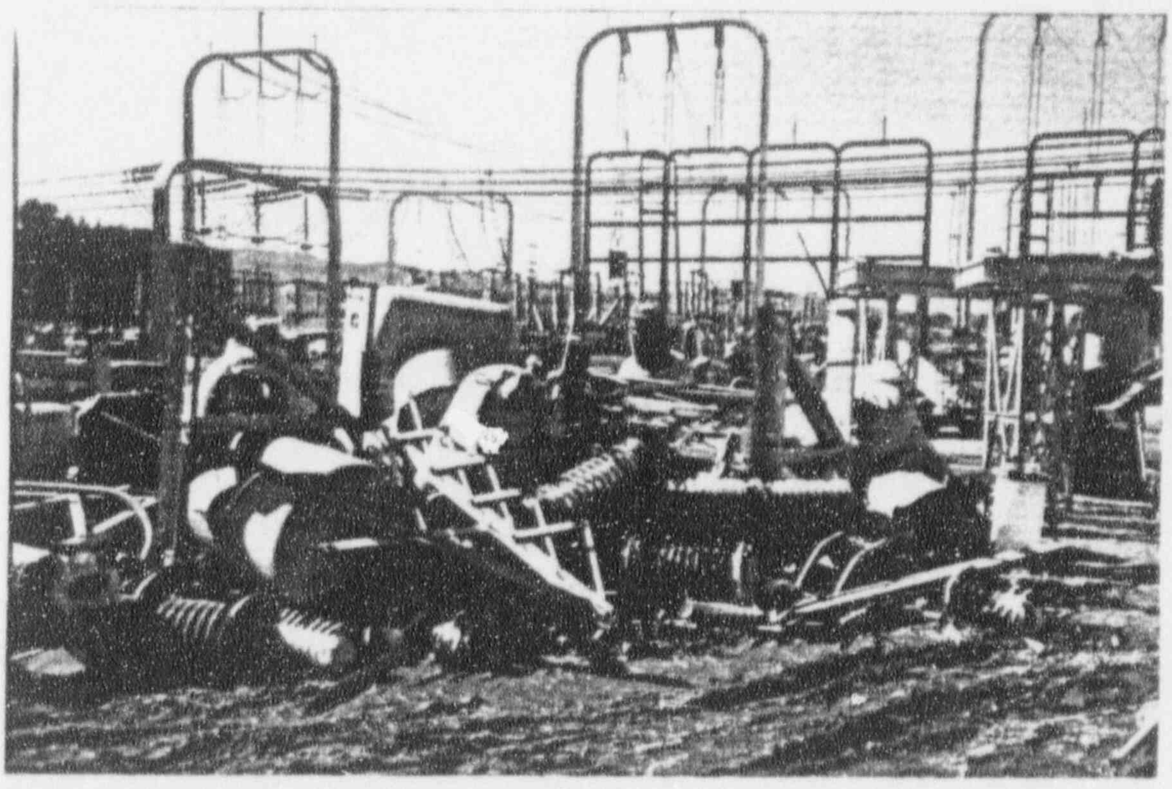
Figure 2. Map of faults in the Los Angeles region (from PG&E Reconnaissance Report on the Northridge Earthquake of January 17, 1994, Figure 3).



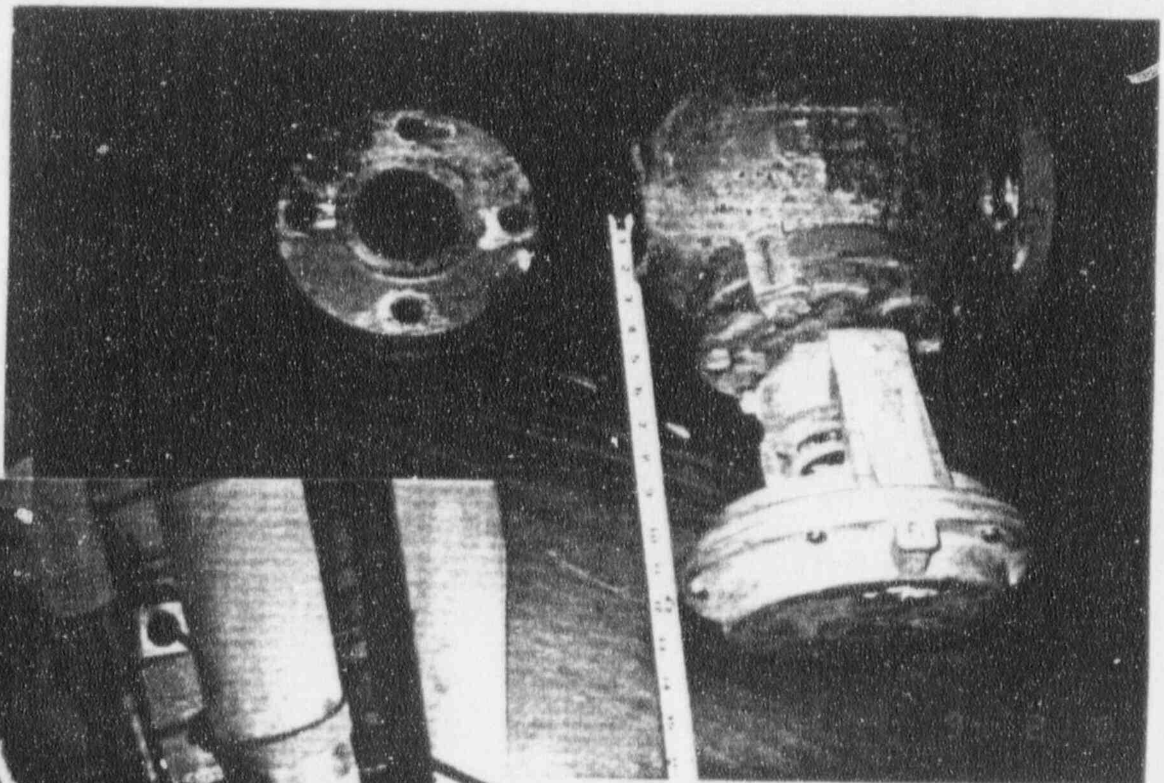


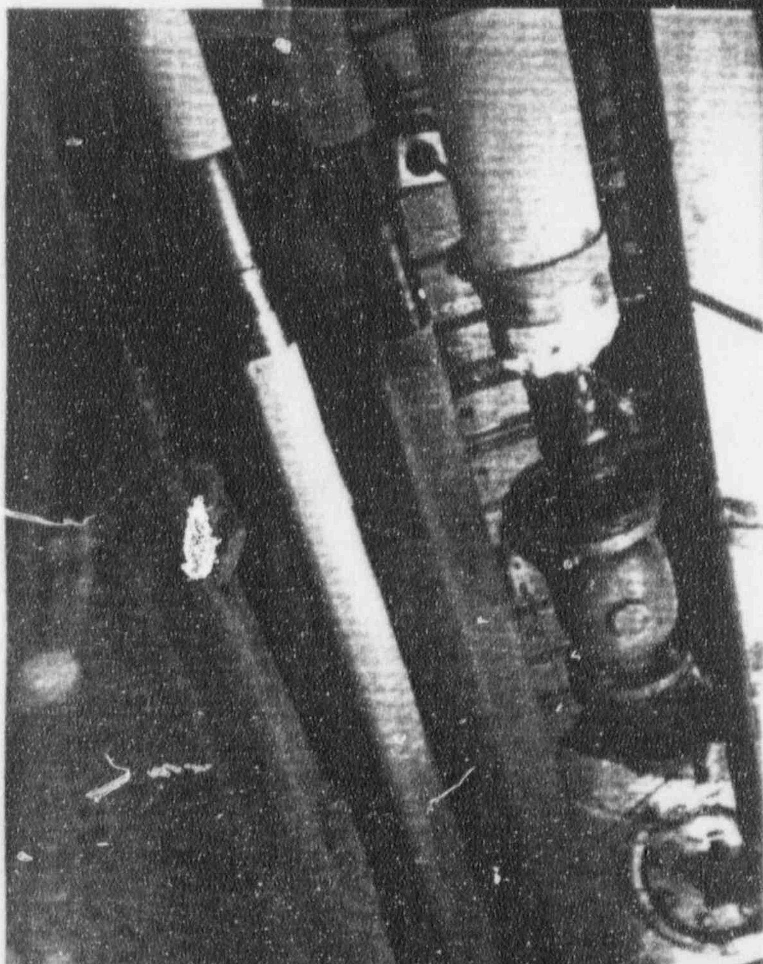
Figures 3 and 4. A ductile failure in the exterior columns of the California State University at Northridge parking structure (Figure 3). Precast column elements were poorly tied to adjacent columns (Figure 4). Also, in Figure 4 note the short development length of the reinforcement steel and the short bearing seat.



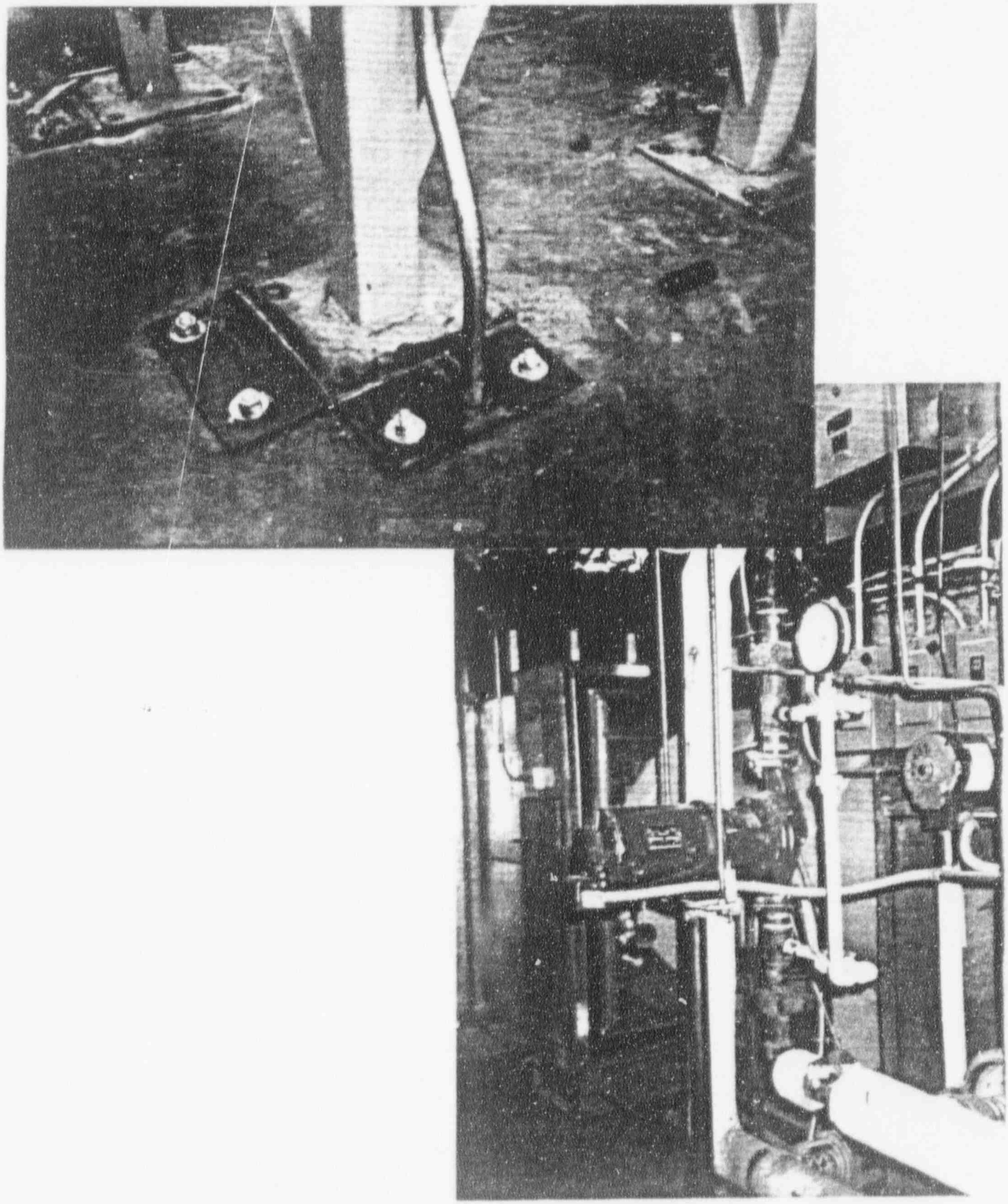


Figures 5 and 6. Mechanical and electrical equipment (Figure 5) located in some power systems was well anchored. However, there was major damage to ceramic insulators. Figure 6 depicts the "grave yard" not the insitu location.

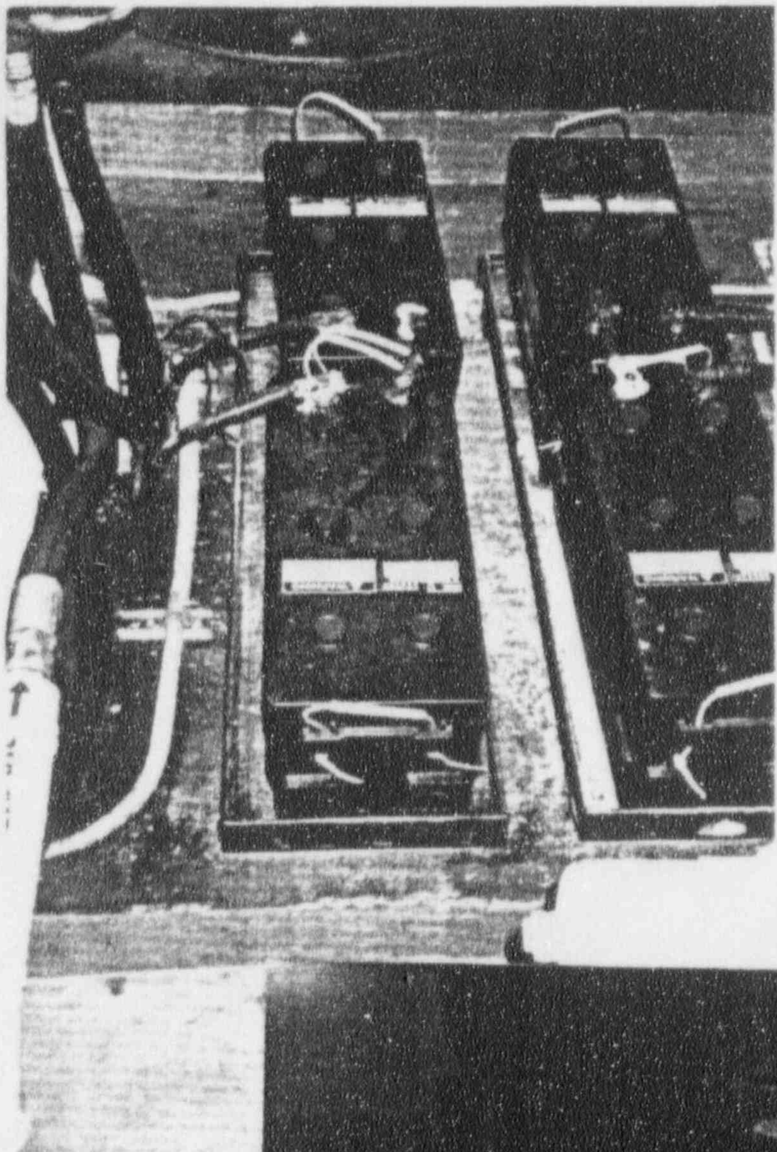


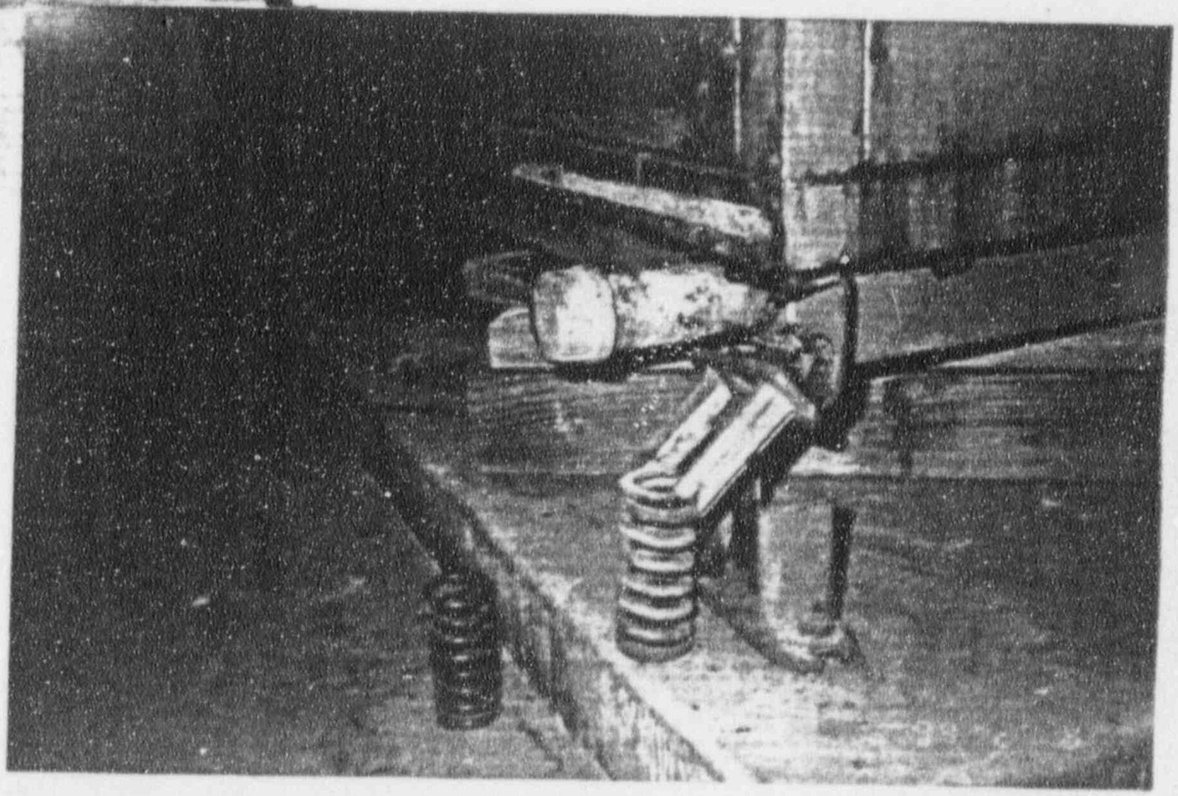


Figures 7 and 8. Possible inertia failure of a 3-inch valve body. Figure 7 shows the failed valve; Figure 8 shows the insitu location of the replacement valve.

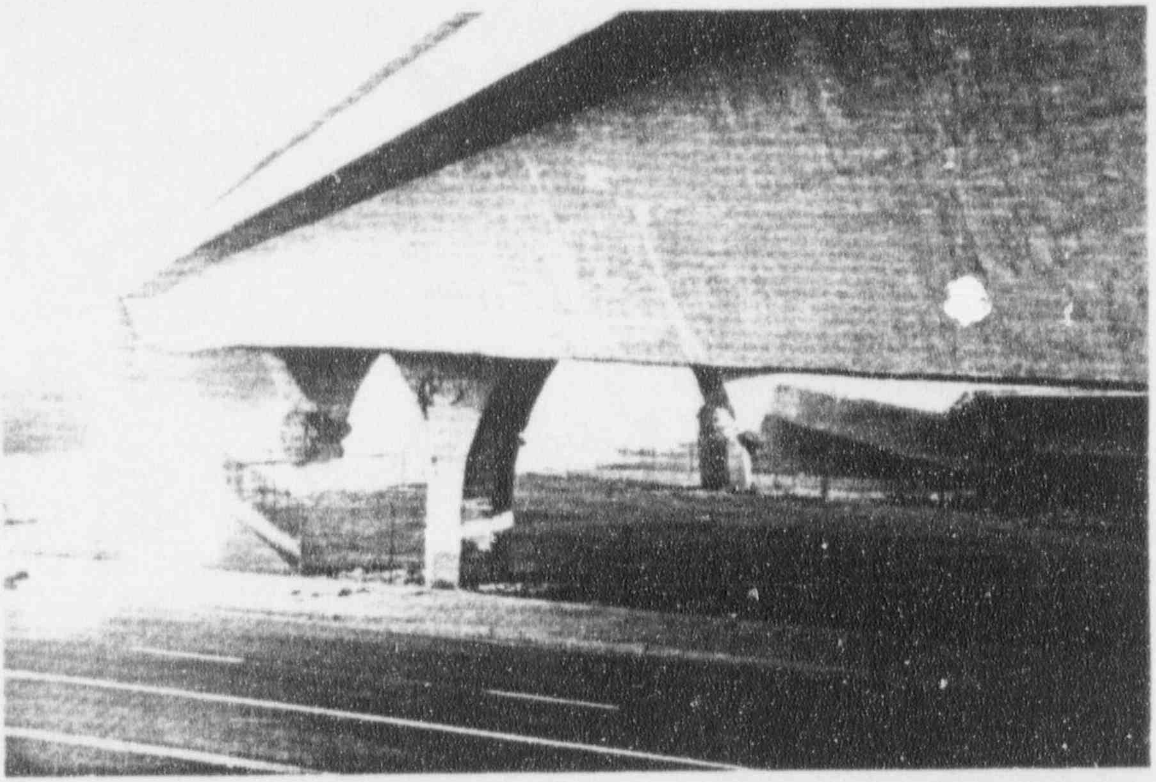


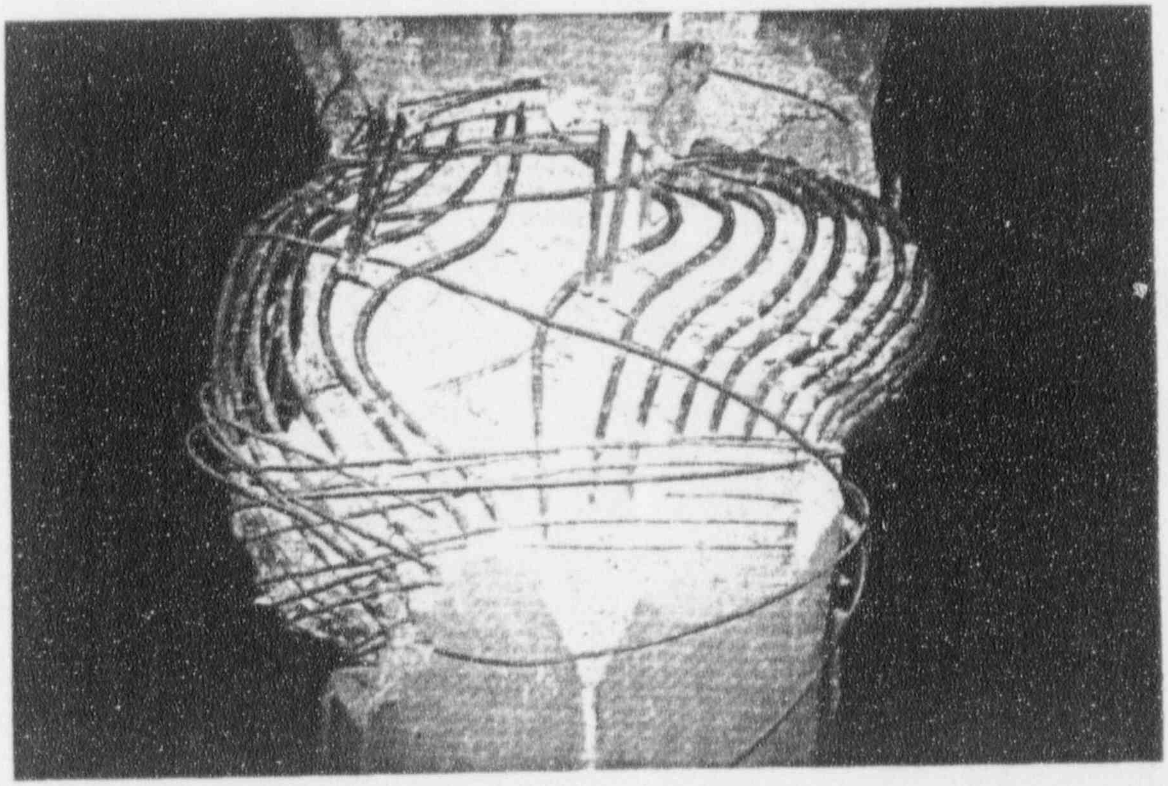
Figures 9 and 10. Kickplates butt welded to the original support plates were added as a post-earthquake upgrade to air handlers (Figure 9). The original anchorage will be replaced by through bolts from the floor below. Rod hung pumps did not fail (Figure 10). The support below the pump is a post-earthquake upgrade.





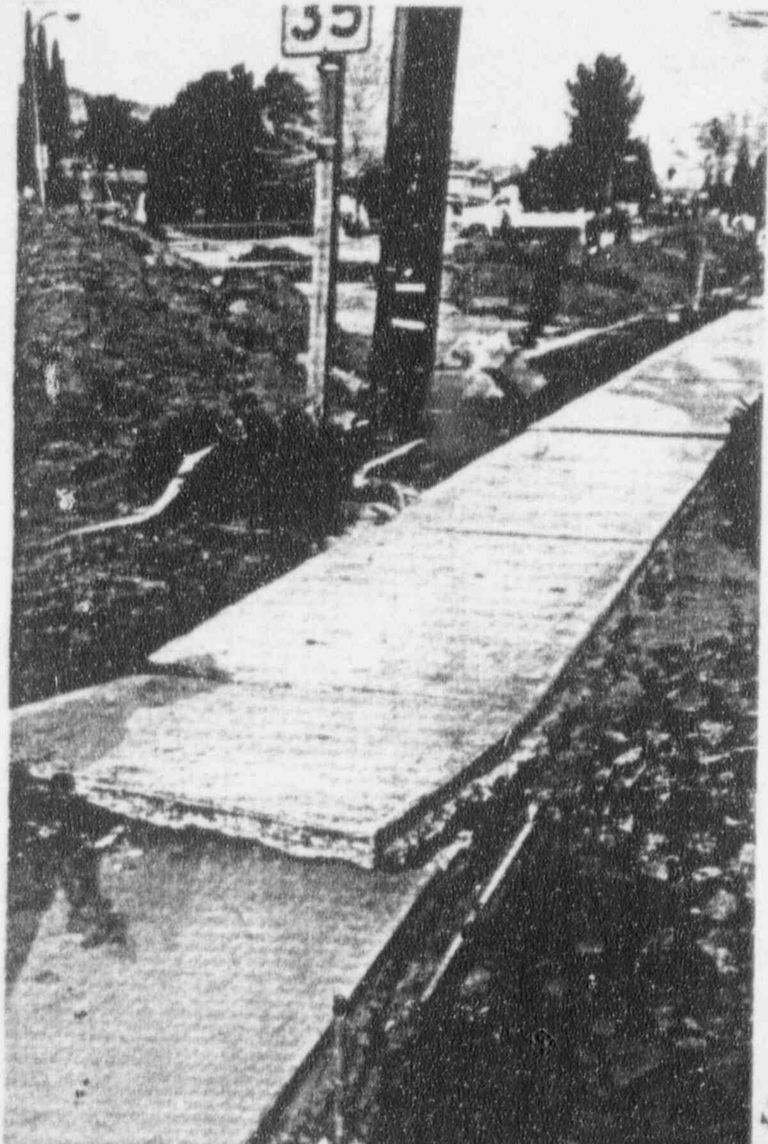
Figures 11 and 12. The batteries (Figure 11) displaced because they were not supported or confined. Isolators located on air handlers were broken (Figure 12).

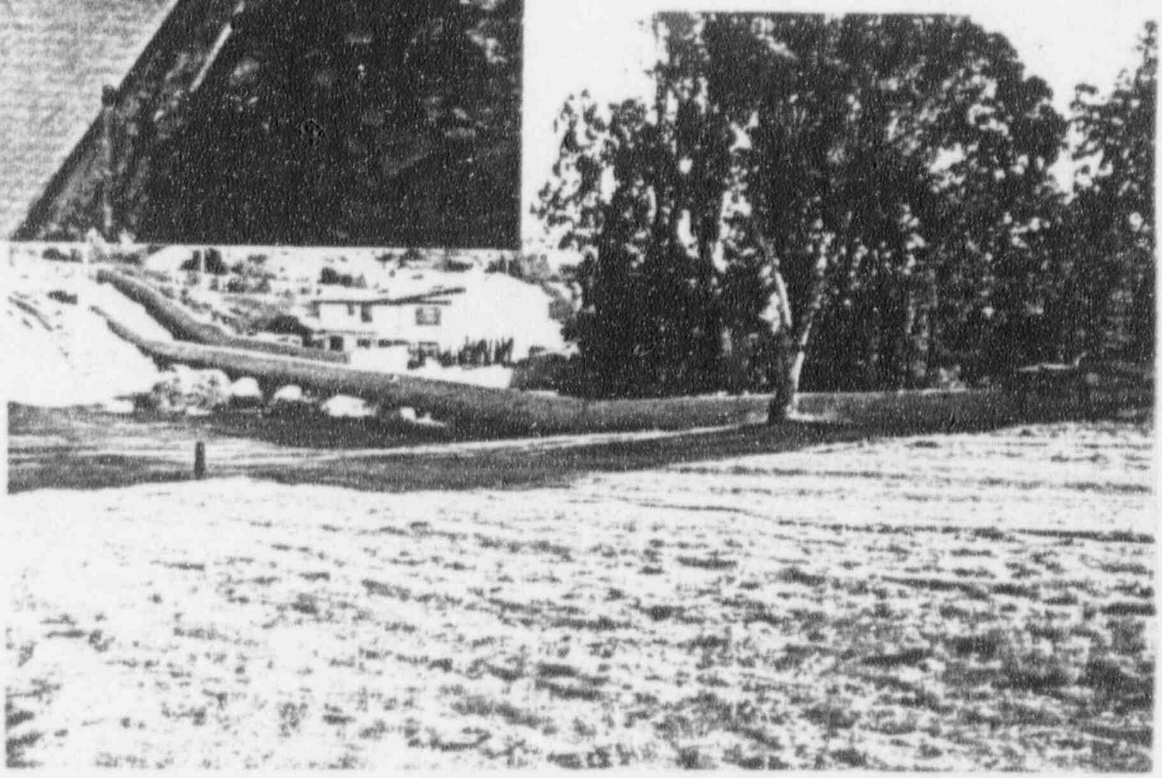




Figures 13 and 14. The bridge columns lost core confinement of the concrete and thereby lost their ability to support large vertical loads.

Figures 15 and 16. Several lifelines were severely impacted. These lifelines included 40- and 60-inch diameter water lines and 6- and 22-inch diameter gas lines.





Figures 17 and 18. A 2-foot length of the north portion of the sidewalk moved over the south portion of the sidewalk (Figure 17). In contrast to the buried pipes shown in Figures 15 and 16, this above-ground, 5½-foot diameter pipeline (Figure 18) appears to have very little distress. The location of this pipeline is a mile closer to the epicenter than the pipes shown in Figures 15 and 16.