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ESTUDIOS DE CAMPO

REPORT ON THE JANUARY 17, 1994 NORTHRIGDE EARTHQUAKE SEISMOLOGICAL AND ENGINEERING ASPECTS

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CENTRO NACIONAL DE PREVENCION DE DESASTRES

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COORDINACION DE INVESTIGACION

AREAS DE RIESGOS GEOLOGICOS Y DE ENSAYES SISMICOS

CUADERNOS DE INVESTIGACION

Estudios de Campo

P R E S E N T A C I O N

La Coordinación de Investigación del Centro Nacional de Prevención de Desastres realiza estudios sobre las características de los fenómenos naturales y de las actividades humanas que son fuentes potenciales de desastres, así como sobre las técnicas y medidas que conducen a la reducción de las consecuencias de dichos fenómenos.

A menudo el personal técnico del CENAPRED realiza estudios de campo sobre el origen, desarrollo y efectos probables de fenómenos productores de desastres y sobre los daños producidos en diferentes sistemas por desastres. En este último rubro se encuentran las misiones de evaluación de daños sísmicos.

El CENAPRED ha emprendido la publicación de esta serie, dentro de los Cuadernos de Investigación, para difundir las observaciones de los trabajos de mayor interés.

CONTENT

PART A. SEISMOLOGICAL ASPECTS ON THE JANUARY 17, 1994 NORTHRIDGE EARTHQUAKE

1. INTRODUCTION

This is a report of seismological investigations of various aspects of the Northridge, California earthquake (M = 6.7) that occurred approximately 50 km northwest of the Los Angeles area on January 17, 1994. During the period between January 28 and February 1, we had a chance of visiting Seismological Laboratory, California Institute of Technology and United State Geological Survey, Pasadena, to investigate seismological and strong motion data of the earthquake, and the Northridge, Sylmar and San Fernando areas to investigate the general features of structural and ground damage due to this earthquake.

The following description includes two parts; one is the fundamental seismological information mainly based on the data obtained by Caltech and USGS, and the other is based on the strong motion observation data provided by Division of Mines and Geology, California Department of Conservation, USGS and School of Engineering, University of Southern California. The earthquake damage investigated will be described in a separate report.

2. SEISMOLOGICAL INFORMATION

2.1 Main shock

The main shock of the present earthquake occurred near the center of Northridge city about 50 km northwest of downtown Los Angeles at 04 h 30 m 51.4 s (PST) on January 17, 1994. The hypocenter was located at 34°13'N, 118°32'W at a depth of about 18 km. This is the point at which the rupture started. The epicentral area is located between a few geological faults trending east-westwards in the Los Angeles basin (as shown in Fig. 1), but its location does not seem to be directly associated with any of the pre-existing surface faults. The map (Fig. 1) shows that there have been quite a number of earthquakes in this area, and the present earthquake took place just west of the 1971 San Fernando earthquake (M = 6.6).

Source Parameters

The focal mechanism of the mainshock derived from the P-wave first motions indicates a W30°N striking nodal plane dipping 35°-45° to the south. On the other hand, the moment tensor solution calculated from long-period teleseismic waves gives its strike ranging between W21°-31°N and a southwestward dip of 42°-51° (Figs. 2 and 3), which is also supported by the spatial distribution of aftershocks as described below. The above evidence indicates a thrust-type mechanism on a southwestward dipping fault. The solution also provides estimates of seismic moment to be $Mo = (0.88 - 1.50) \times 10^{26}$ dyne cm, from which the corresponding moment magnitude is found to be $Mw = 6.6 - 6.7$.

2.2 Aftershocks and Fault Characteristics

More than 2,500 aftershocks have been recorded during 7 days up to January 24 by the southern California network operated jointly by several institutions. The numbers of aftershocks with relatively larger magnitudes were:

2 shocks for $5.0 < M < 5.6$

35 shocks for $4.0 < M < 4.9$

272 shocks for $3.0 < M < 3.9$

Another two large aftershocks with $M = 5.0$ and 4.5 occurred on January 29, which are not included in the above observations. The temporal decay of these aftershocks follows a normal pattern for California earthquakes, but is slightly more quickly than the average sequence. The Northridge aftershocks also seem to be a bit more energetic than the average.

Fig. 4 shows the horizontal distribution of the aftershocks that occurred during the period between January 22 and 27. The aftershock zone extends for 30 km in the east-west direction from San Fernando to Santa Susana, and for about 25 km from Northridge in the south to the Santa Clarita Valley in the north. The northernmost aftershocks reach the San Gabriel fault. It can be seen from Fig. 1 that part of these aftershocks were located within the aftershock area of the 1971 San Fernando earthquake. The main shock epicenter of the present earthquake was located near the southern edge of the aftershock zone. Fig. 5 shows the depth distribution of some of the aftershocks projected onto the vertical cross section along A-A' in Fig. 1. The distribution clearly indicates a northeast-southwestward slope of about 42° extending for about 20 km, which is almost consistent with the dip derived independently from the moment tensor fault-plane solution for the main shock. The main shock hypocenter was located near the deepest portion of the aftershock distribution. From the above evidence, it may be inferred that the main shock rupture initiated from the deepest point at 18 km and propagated upwards and northeastward to the shallowest point at depths of about 2 - 3 km. It was also found that most of the 300 larger aftershocks have thrust faulting mechanisms similar to that of the main shock, although a few of them show normal or strike-slip movement.

Figs. 6 and 7 show the horizontal and depth distributions of aftershocks that occurred in the period of January 26 to 29, respectively. Two large circles indicates the two larger aftershocks of January 29. The larger one (M = 5.0) took place very close to the main shock hypocenter with almost the same focal mechanism, while the lesser one (M = 4.5) was located in a very shallow position probably on the Santa Susana fault as indicated in Fig. 6, and its mechanism was of strike-slip type. Fig. 9 plots the spatio-temporal pattern of the aftershock sequence taking place in the area enclosed in Fig. 8, where the ordinate corresponds to the distance measured along B-B'. No specific clustering has been identified either in space or in time during this period, except 3 successive, moderate-size shocks with magnitudes between 4.3 and 4.5 on January 24.

2.3 Surface Faulting and Tectonics

1) Rupture on the ground surface has been identified along the south side of Potreo Canyon which is located just south of Castaic Junction. It extends about 5 km eastward from its junction with the Santa Clara river valley. About 10 - 20 cm offset has been observed on a previously unmapped south-dipping thrust faults (Caltech). However, the relationship between this surface faulting and the main shock fault plane of the present earthquake is still not known at this moment.

2) GPS measurements with high accuracy have been made on about 25 sites over the epicentral region by USGS, SCEC, JPL and others to detect possible surface displacements. Preliminary

results indicate that a GPS station on the ridge of the Santa Susana Mountains recorded displacements upward by 5.9 cm and northward by 2.4 cm during the earthquake, and that a second site north of Castaic Junction and east of I-5 moved down by 1.4 cm and south by 0.6 cm.

3) Seismologists and geologists from Seismological Laboratory, Caltech presented a hypothesis on the possible relationship between general tectonics of this region and fault movements that caused the present earthquake, as illustrated in Fig. 10. The hypothesis postulates the existence of the Santa Monica Mountains Fault with a low dip beneath the region extending from the Santa Monica Mountains to the San Gabriel Mountains. It is suggested that the main shock rupture initiated at a depth of about 15 km just beneath Northridge on the postulated fault and then propagated obliquely upwards on a southwestward-dipping fault, yielding thrust movement. This main movement might have triggered another slip on buried faults parallel and perpendicular (Santa Susana Fault) to the main shock fault. It might be possible for the hypothesis to account for various observations.

4) Seismologists from Southern California Earthquake Center (SCEC) affiliated institutions: Caltech, SDSU, UCLA, UCSB, UCSD, USC, Lamont, and the USGS in Pasadena, Menlo Park and Denver, have installed more than 75 seismometers to record aftershocks from the Northridge earthquake, most of which have been deployed in the San Fernando Valley and northern Los Angeles areas. It is expected that the data from these temporary stations will help locate the aftershocks more accurately and trace the temporal variations of aftershock sequence.

2.4 Waveforms Recorded by Broadband Seismographs

Figs. 11 and 12 show the broadband seismograms recorded at Pasadena during the main shock and one ($M = 5.9$) of the large aftershocks, which give the ground-velocity (in cm/sec) waveforms. It is to be noted that the aftershock record involves period components longer than 8 sec and lasts for more than 40 sec. The recorded waveforms are now being investigated by many seismologists.

3. STRONG MOTION DATA

In Southern California particularly around the Los Angeles area, a large number of strong motion stations have been installed, including the CSMIP (California Strong Motion Instrumentation Program) network operated by the California State Division of Mines and Geology, the NSMN network (National Strong Motion Network) operated by U.S. Geological Survey, and the LASMA (Los Angeles Strong Motion Array) operated by University of Southern California. During the Northridge earthquake, strong ground motions have been well recorded by various types of accelerographs at these stations.

1) The locations of the selected CSMIP stations in the Los Angeles area are plotted on maps in Figs. 13 and 14. The peak ground accelerations (unit: g) recorded at these 68 stations are summarized in Table 1, together with the station coordinates and their approximate epicentral distances (CSMIP, 5th Quick Report, Jan. 25, 1994). Some of the large accelerations recorded on the free field, at the base and on the top of structures are given below.

No.	24655	Los Angeles	6-story parking	(D=32 km)	1.21 g H	(st)
	24087	Arleta	Fire Station	(D= 8 km)	0.59 g V	(gr)
	24514	Sylmar	Olive View Hospital	(D=15 km)	0.91 g H, 0.60 g V	(gr)
					2.31 g H	(s6)
	24670	Los Angeles	I10/405 Junction	(D=23 km)	1.00 g H, 1.83 g V	(br)
	24416	Tarzana	Cedar Hill Nursery	(D= 7 km)	1.82 g H, 1.18 g V	(gr)
	24386	Van Nuys	7-story Hotel	(D= 6 km)	0.47 g H, 0.30 g V	(bs)
	24207	Pacoima Dam	Dam Left Abutment	(D=18 km)	2.3 g H, 1.7 g V	(dm)
					0.44 g H, 0.20 g V	(dm)

st: structure, gr: ground surface, s6: 6th floor, br: bridge, bs: basement, dm: dam

It is to be remarked here that all three components from the Tarzana free-field station, about 7 km south of the epicenter, recorded accelerations over 1.0 g for 7 - 8 sec., with a peak horizontal acceleration of 1.8 g. The Upper Left Abutment instruments at the Pacoima Dam, which had recorded high acceleration over 1.0 g during the 1971 San Fernando earthquake, again recorded accelerations greater than 1.7 g on all three components, while the Dam downstream records indicate accelerations less than 0.4 g comparable to the record at the Dam base. The former one may have been strongly affected by local topography. High accelerations over 1.0 g have also been recorded at a 6-story parking structure in Los Angeles, at the 6-story Olive View Hospital in Sylmar, and on a bridge at I5/405 Junction in Los Angeles. Figs. 15 to 19 provide the strong motion accelerograms recorded at Sylmar, Tarzana and Pacoima Dam. These records are characterized by large-amplitude S waves lasting for 7 sec.

2) The NSMS stations also recorded high ground accelerations very close to 1.0 g at two sites near the epicenter as shown below.

Sepulveda V. A. Hospital	(D= 8 km)	0.94 g H, 0.48 g V	(ground level)
Jensen Filter Plant	(D=12 km)	0.98 g H, 0.52 g V	(ground level)

3) A number of the USC stations located in the Northridge and Los Angeles areas recorded large accelerations during the present earthquake. The distributions of peak accelerations exceeding 0.2 g in the horizontal component and 0.1 g in the vertical component are shown on maps in Figs. 18 and 19. It can be seen from these maps that large accelerations have been recorded around and north of the Northridge, at several sites located between the Santa Susana and San Gabriel faults, and also in part of the Los Angeles and Santa Monica areas.

The large accelerations recorded just north of the epicentral area may result from the concentration of seismic energy due to rupture propagation up- and northeast-wards from the deep hypocenter. The relatively large accelerations in the Los Angeles and Santa Monica areas might be attributed partly to local amplification effects from soft sedimentary layers beneath the recording sites and partly to possible movements of the foot-wall block located south of the thrust faulting in the present earthquake.

All the above descriptions are based on the preliminary reports available up to the present, and more detailed investigations are now being made by a number of seismologists and earthquake engineers. We wish to thank our many colleagues, particularly Prof. Hiroo Kanamori, Director of Seismological Laboratory, Caltech, and Dr. Jim Mori, Director of the Pasadena office of U.S. Geological Survey for providing us various data and reports.

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1) California Institute of Technology, U.S. Geological Survey, Southern California Earthquake Center, and Jet Propulsion Laboratory, "The Magnitude 6.6 Northridge, California, Earthquake of January 17, 1994 and Its Aftershocks".

2) Department of Conservation, Division of Mines and Geology, Strong Motion Instrumentation Program, "Quick Reports on CSMIP Strong-Motion Data from the San Fernando Valley Earthquake of January 17, 1994".

3) Porcella, R., E. Etheredge, A. Acosta, E. Anjal, L. Foote and W. Jungblut, "The Ms=6.6 Northridge, California Earthquake of January 17, 1994: Selected USGS Accelerograms Recorded at National Strong-Motion Network Stations".

4) Trifunac, M., M. Todorovska and S. Ivanovic, "Preliminary Report on Distribution of Peak Accelerations During Northridge, January 17, 1994 California Earthquake".

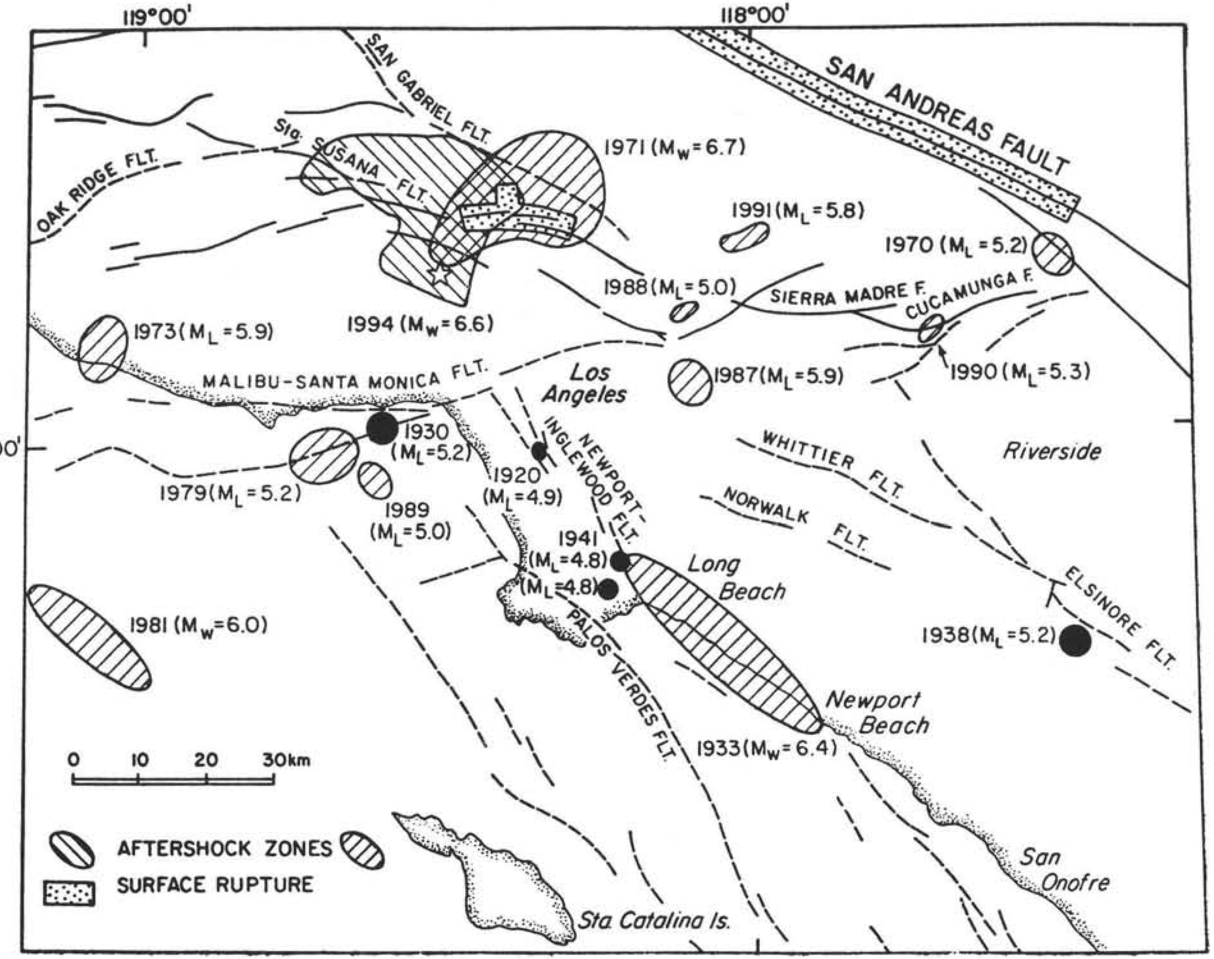

Fig.1 Significant earthquakes of M>4.8 that have occurred in the greater Los Angeles basin area since 1920

```
94/01/17 12:30:51.39
SOUTHERN CALIFORNIA
Epicenter:  34.027 -118.656
mb 6.1     MS 6.6

MOMENT TENSOR SOLUTION
Depth  21          No. of sta: 16
Moment Tensor:    Scale 10**18 Nm
  Mrr= 8.48        Mtt=-8.26
  Mff=-0.21        Mrt=-1.46
  Mrf=-1.48        Mtf= 1.83
 Principal axes:
  T  Val=  8.90  Plg=78  Azm=120
  N       -0.17     11      281
  P       -8.73      4       11

Best Double Couple:Mo=8.8*10**18
                  Mw=6.6
 NP1:Strike=113 Dip=42 Slip= 107
 NP2:       271     50       75
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Fig. 2 Moment tensor solution of the 1994 Northridge earthquake

Mechanism Solutions for the 1/17/1994 Northridge Earthquake

No.	dip	rake	strike	dip	rake	strike	M_0 (10^{26} d-c)	Depth (km)	Source
1	48	122	137	51	59	273	.88	10	Kawakatsu CMT
2	44	105	123	48	76	283	1.2	14	Dreger, waveform
3	42	107	113	50	75	271	.88	21	Needham
4	40	110	125					15	First Motion
5	47	130	137				1.0	20	Thio, Tel B
6				58	85	291	1.6		Thio, TERRA. R and L
7	50	108	126	43	70	279	1.2	17	Harvard
8	65	80	96				1.5	15	Thio CMT
9	48	93	118	42	87	294	1.6		K Global S. R and L

Fig. 3 Mechanism solutions for the 1994 Northridge earthquake

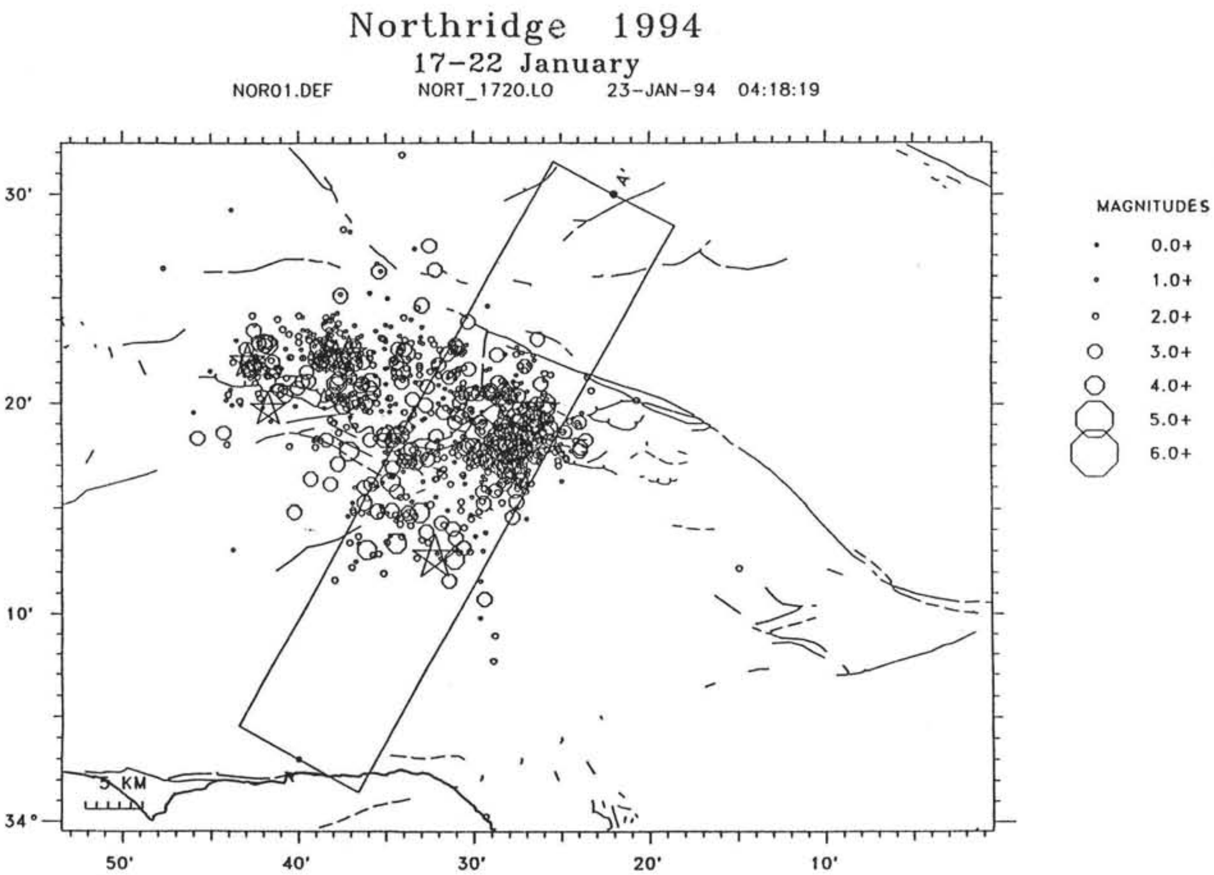


Fig. 4 Horizontal distribution of aftershocks between January 17 and 22

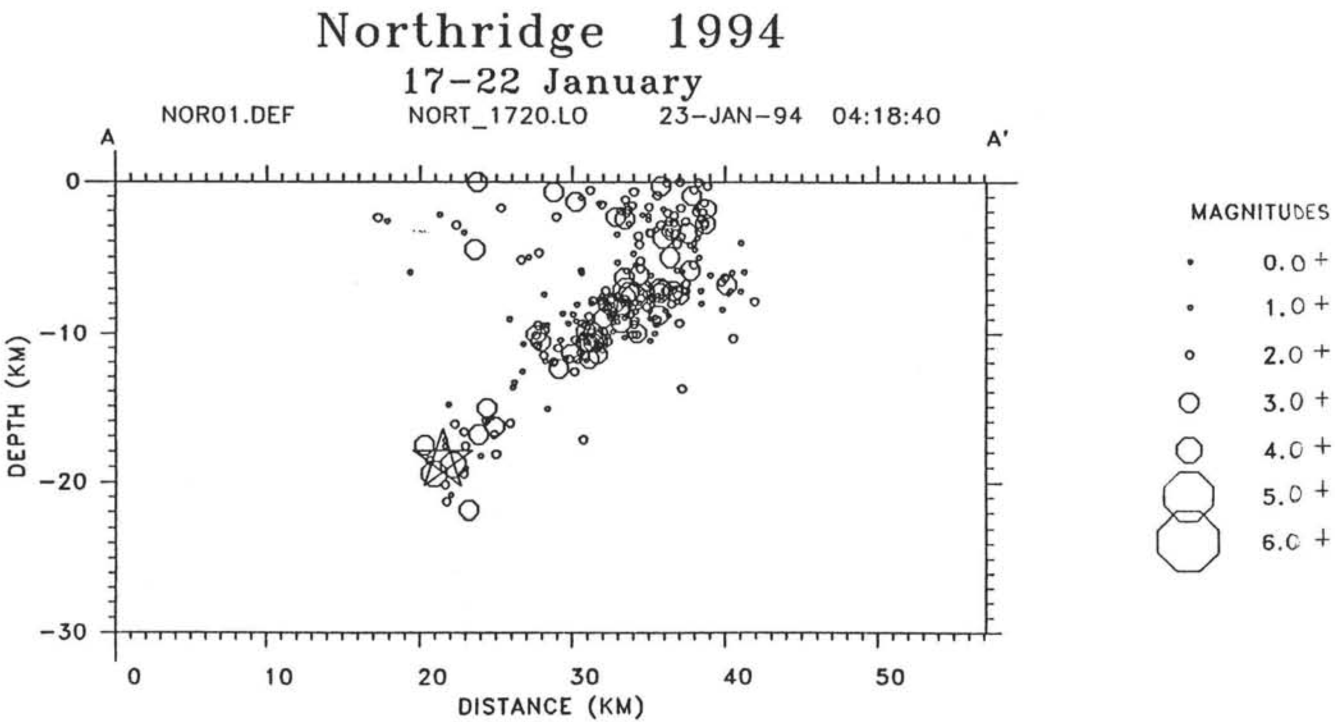


Fig. 5 Depth distribution of some aftershocks

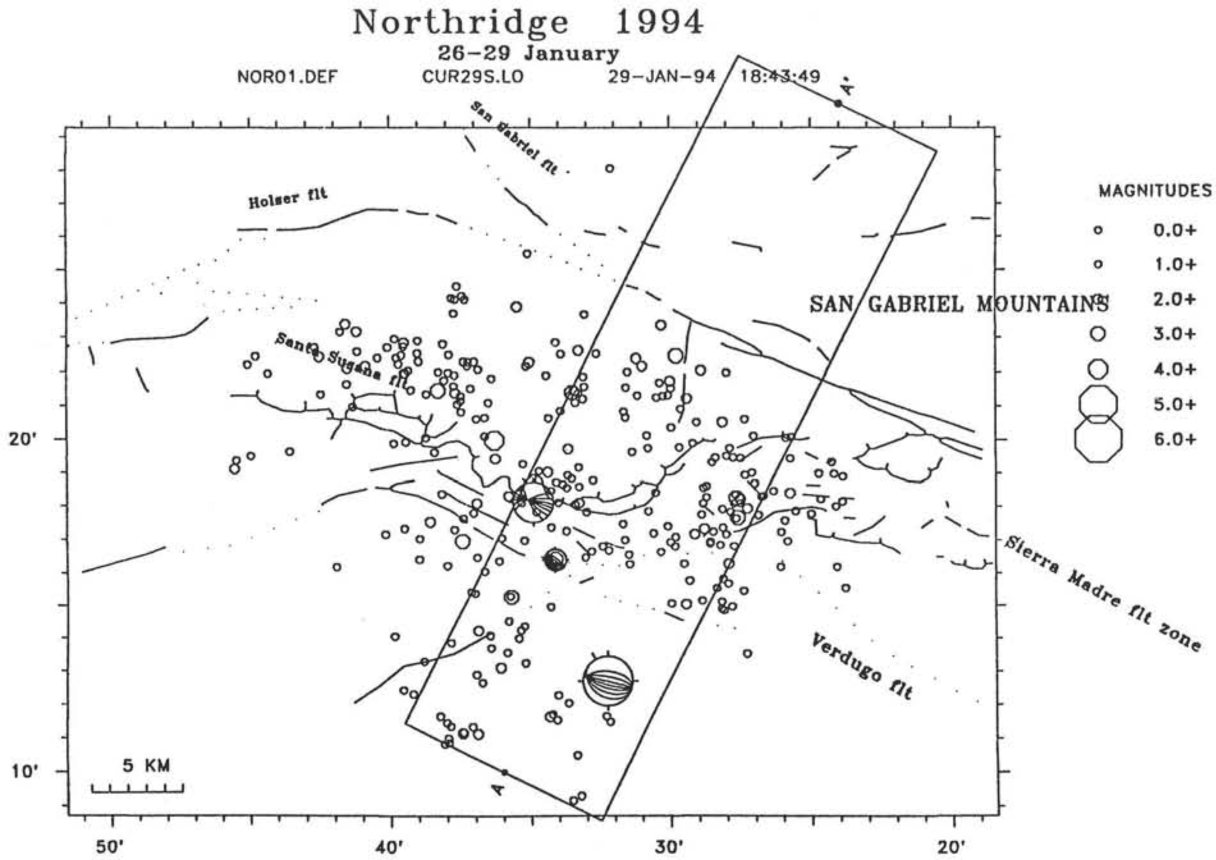


Fig. 6 Horizontal distribution of aftershocks between January 26 and 29

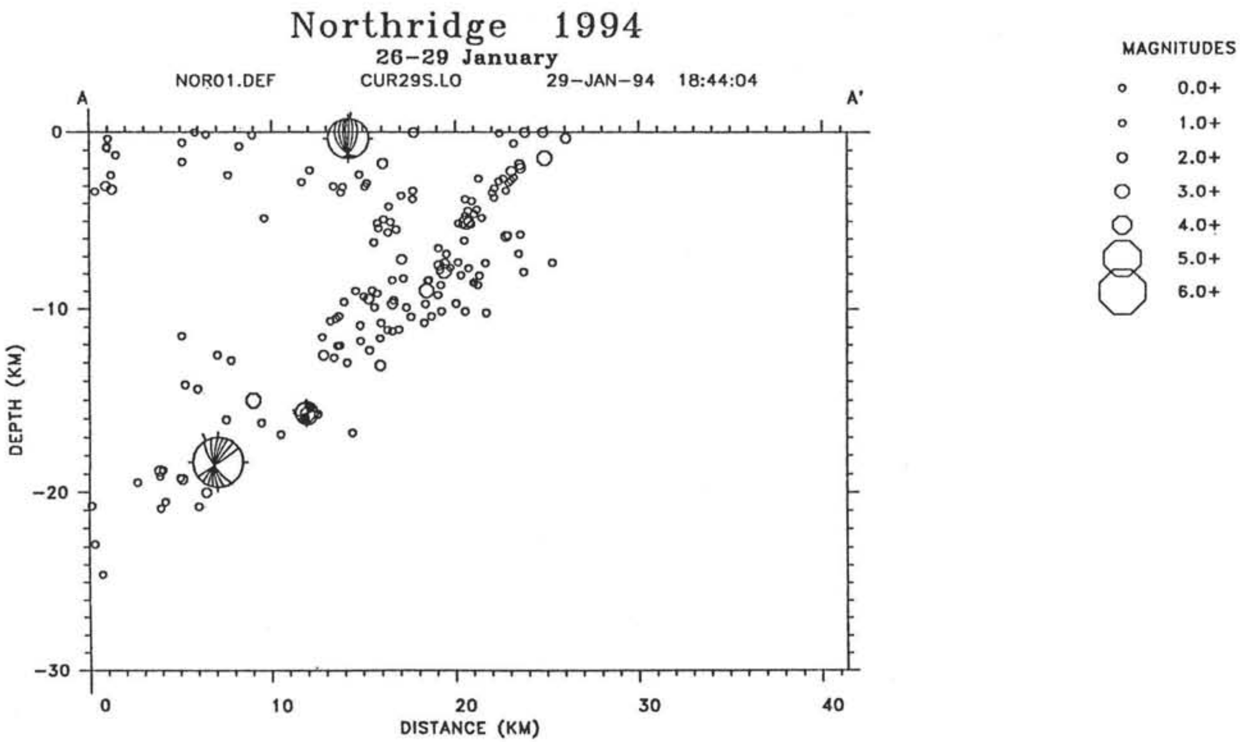


Fig. 7 Depth distribution of aftershocks between January 26 and 29

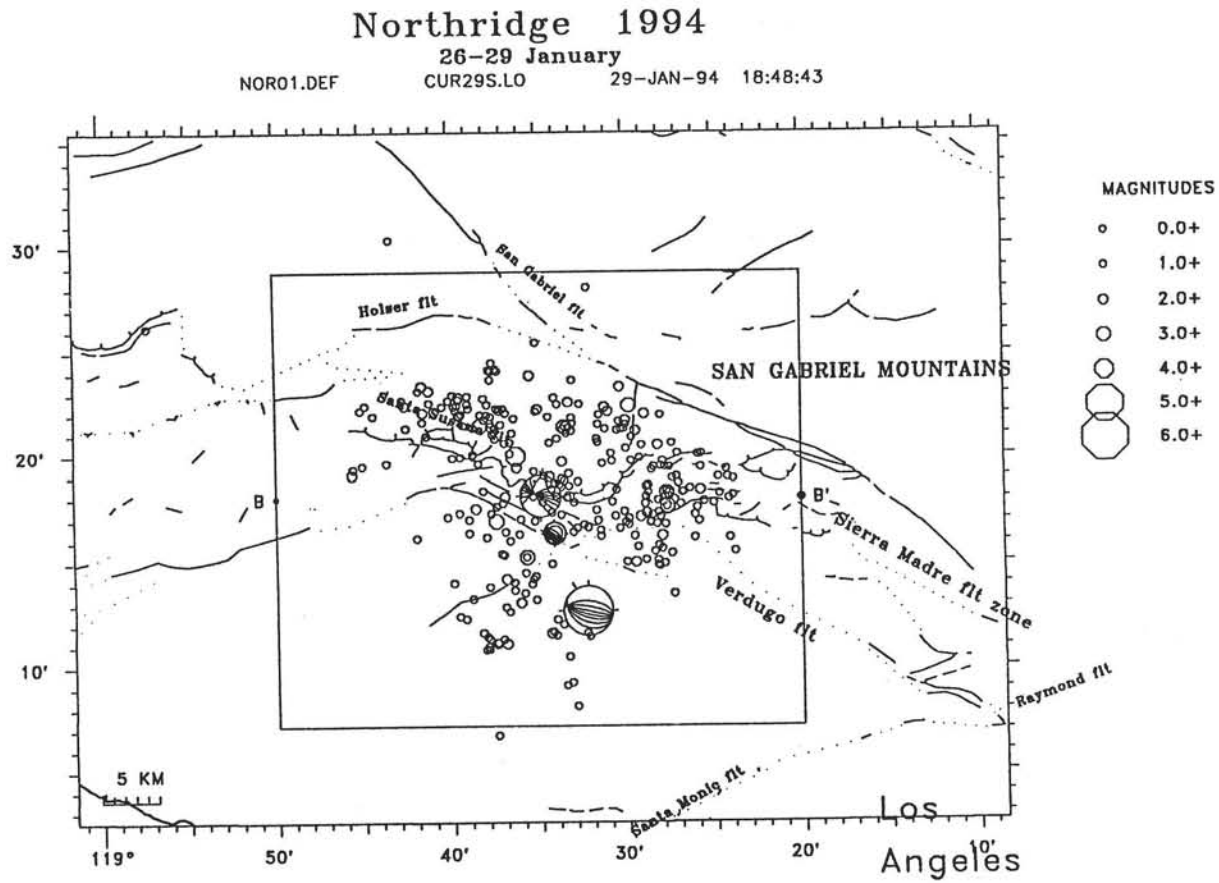


Fig. 8 Horizontal distribution of aftershocks between January 26 and 29

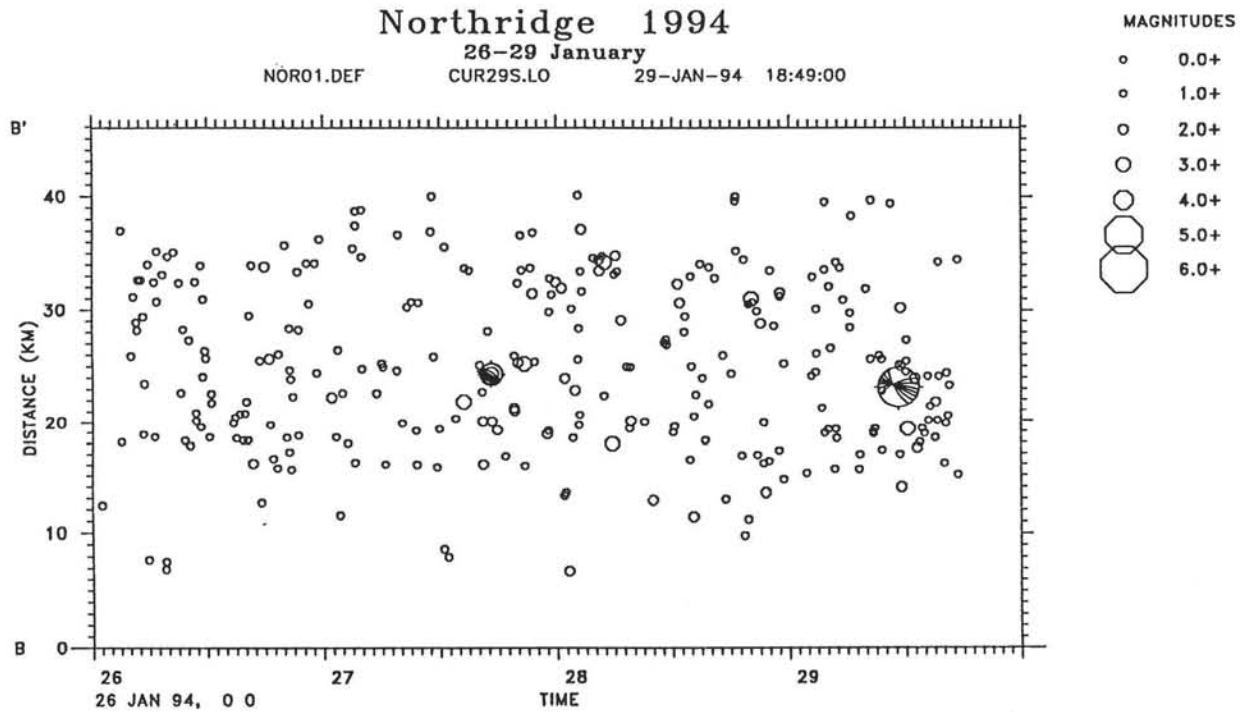
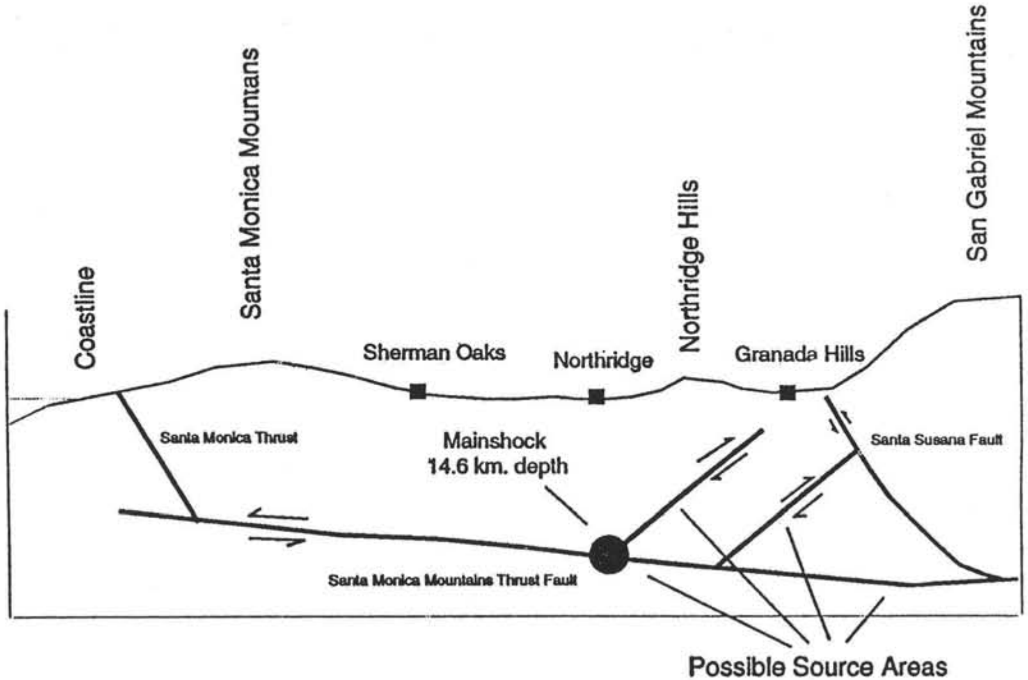


Fig. 9 Spatio–temporal pattern of the aftershock sequence taking place in the area enclosed in Fig. 8



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Pasadena, California

Fig. 10 Northridge earthquake — Preliminary cross section

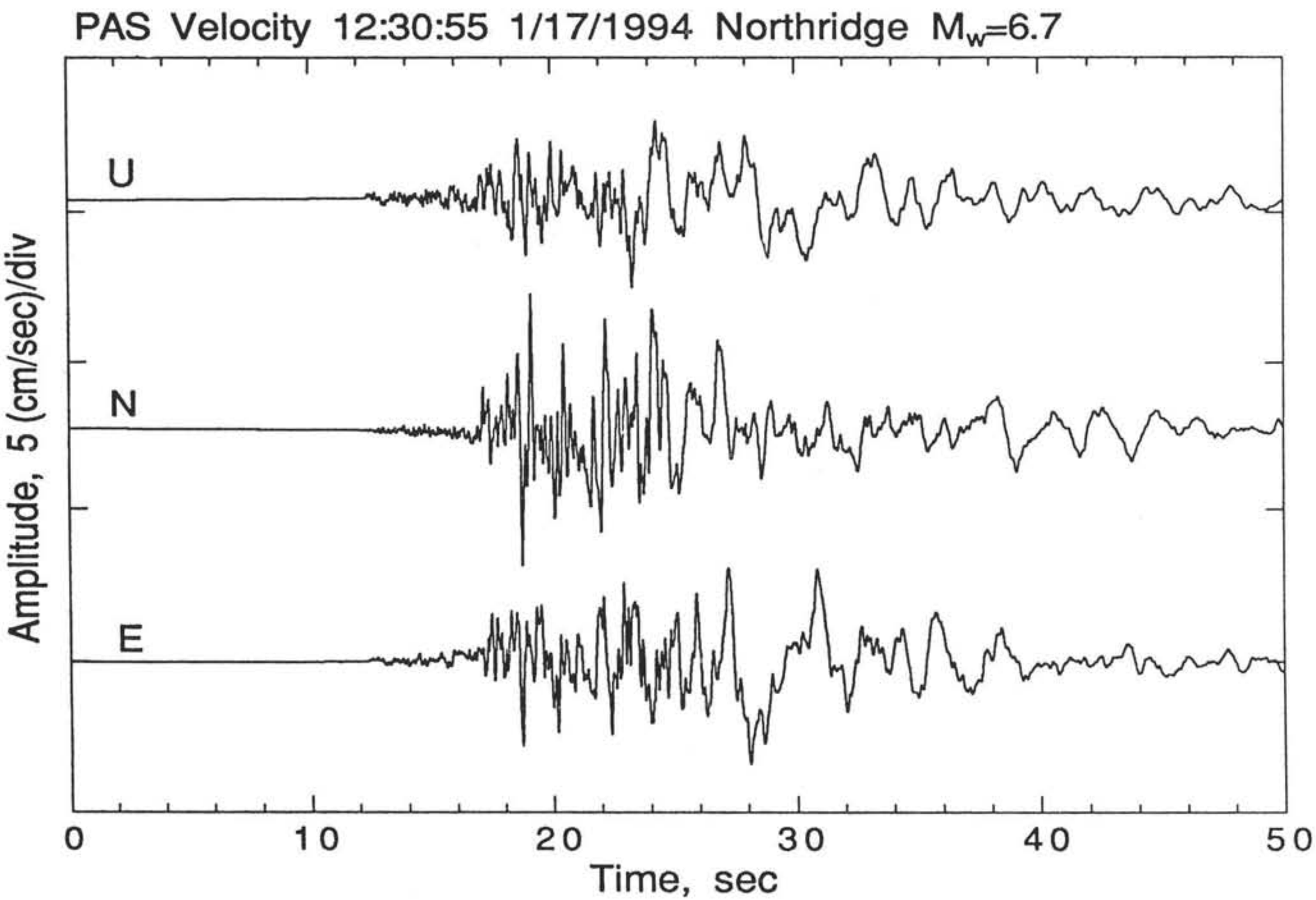


Fig. 11 Broadband seismogram recorded at Pasadena during the main shock

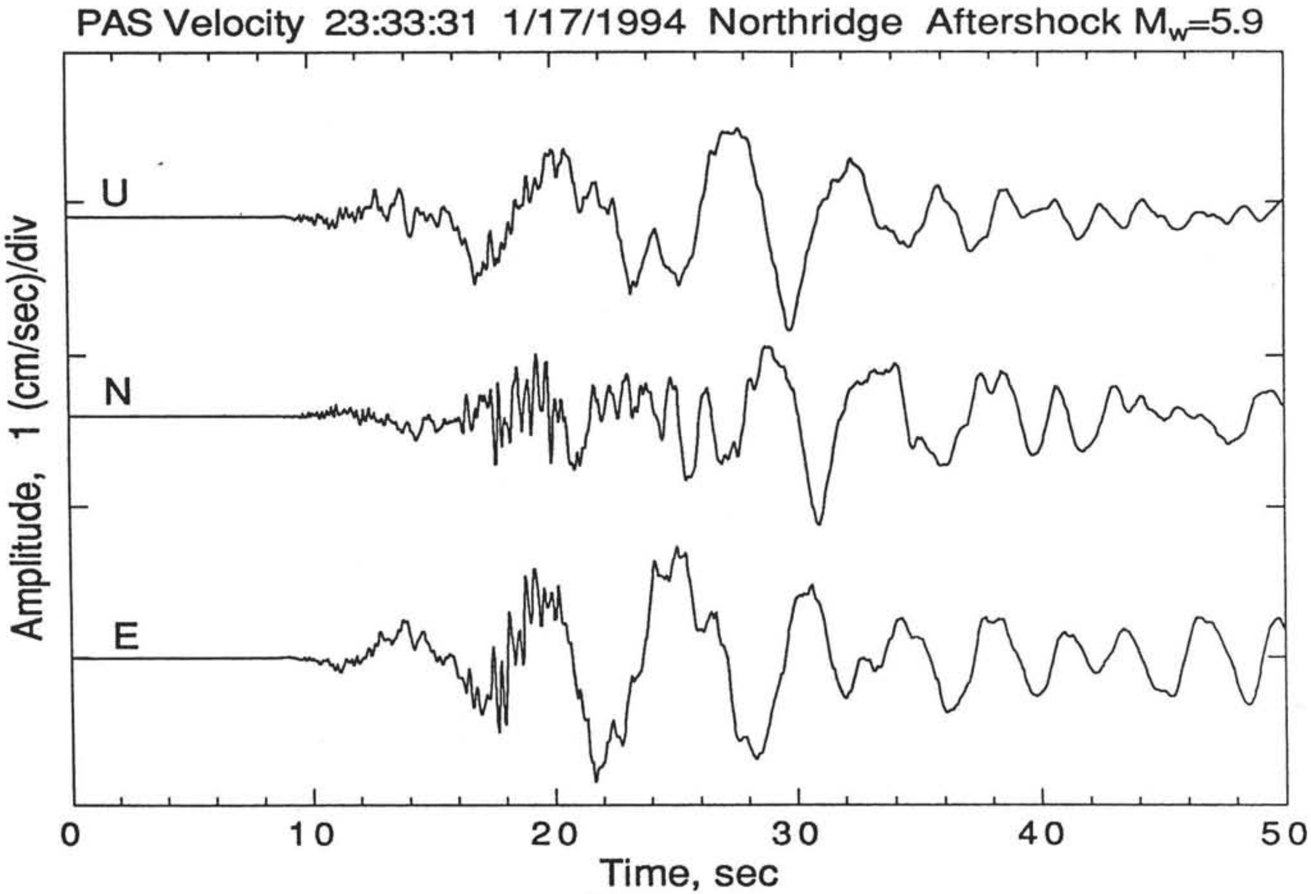


Fig. 12 Broadband seismogram recorded at Pasadena during one (M=5.9) aftershock

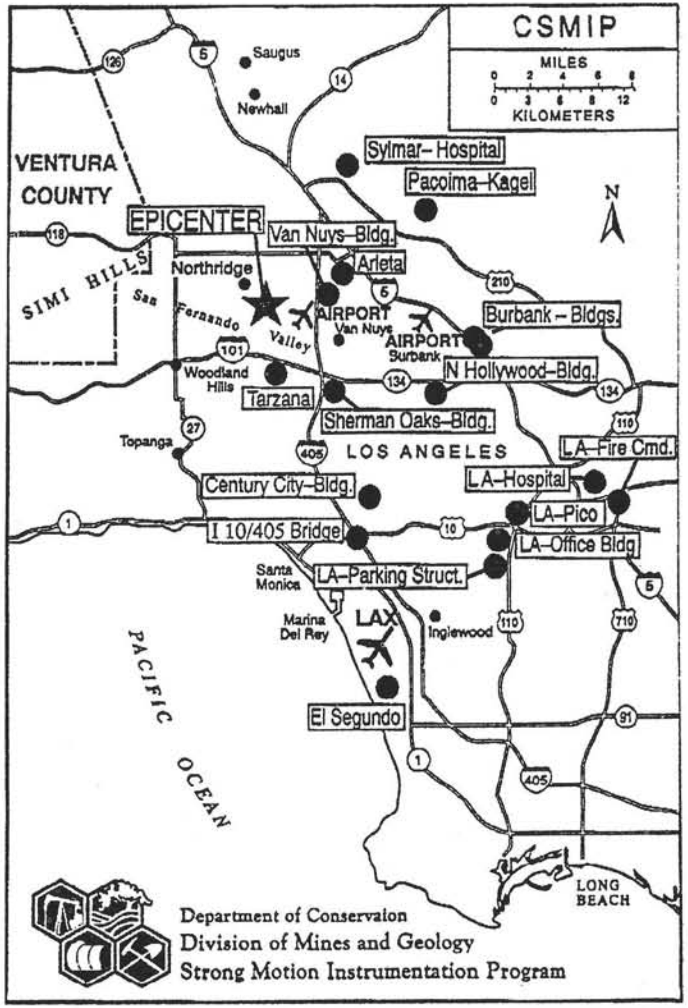


Fig. 13 Selected CSMIP stations in the Los Angeles area

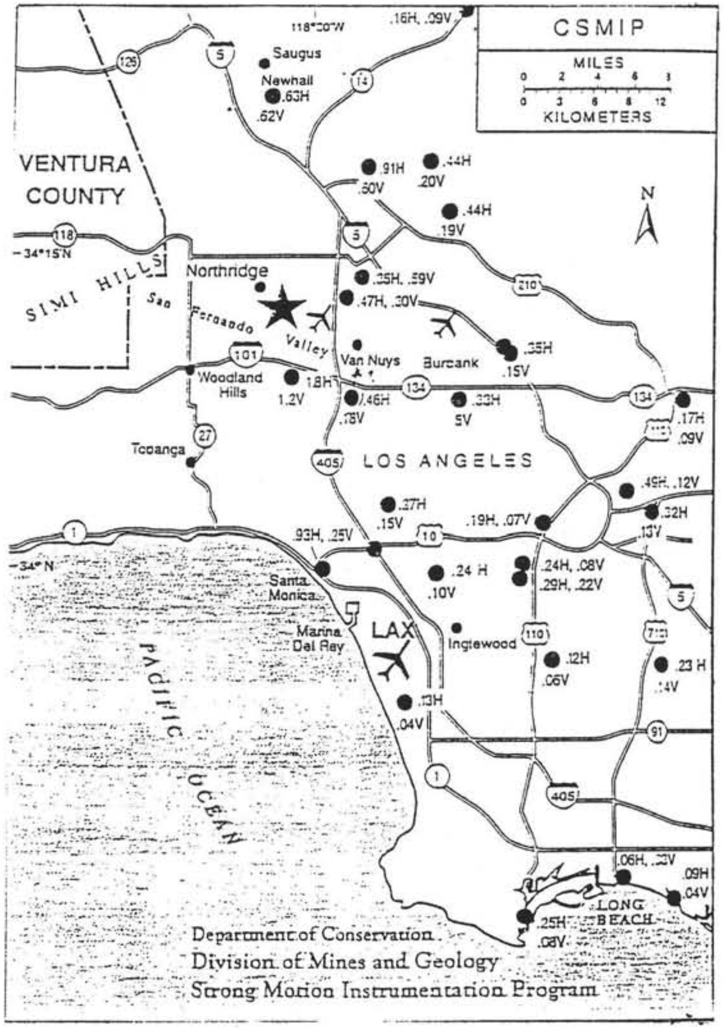


Fig. 14 Selected CSMIP stations in the Los Angeles area

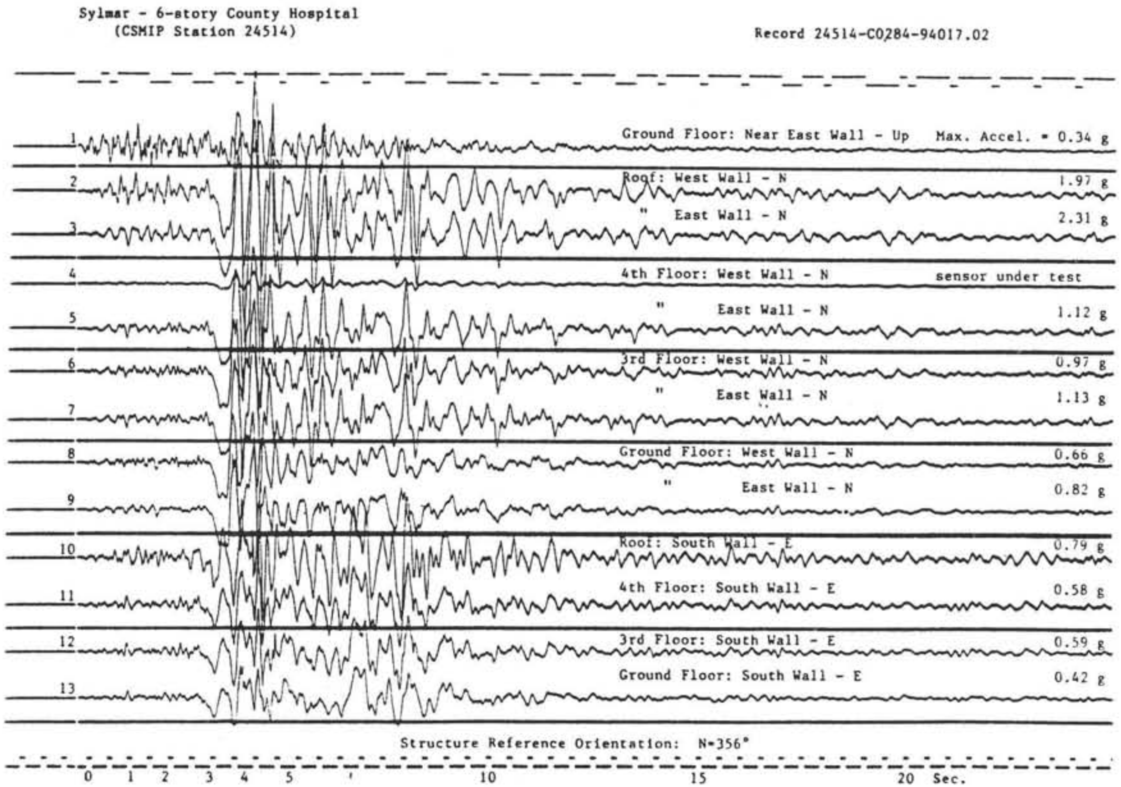


Fig. 15 Strong motion accelerograms recorded at Sylmar 6-story Country Hospital

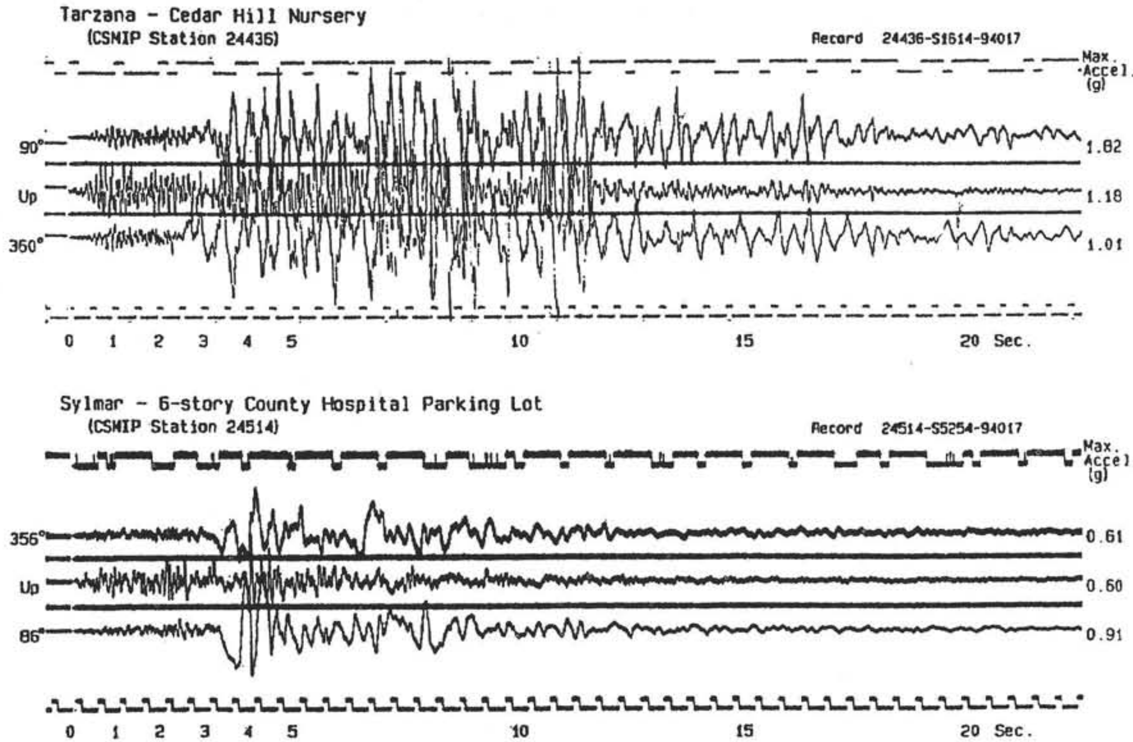
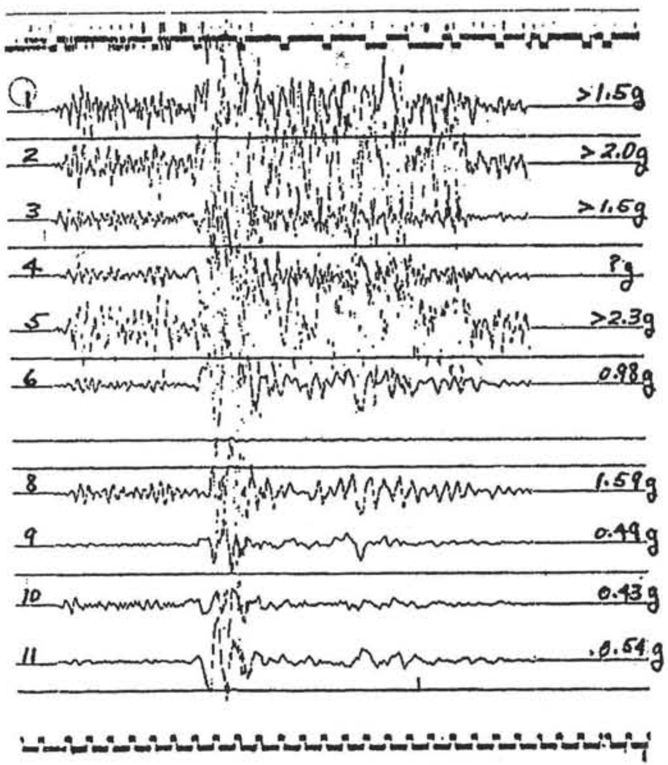


Fig. 16 Strong motion accelerograms recorded at Tarzana and Sylmar
6-story Country Hospital Parking Lot

Pacoima Dam — Northridge Earthquake



1 Crest: Right 1/6 - length Point - T*

2 Crest: Center - T

3 " " - Up

4 " " - R*

5 Crest: Left 1/4 - length Point - T

6 80% Height: Right 1/6 - length Point - T

8 " Left 1/4 - length Point - T

9 Dam Base: T

10 " Up

11 " R

12 Right (North) Abutment: W

13 " Up

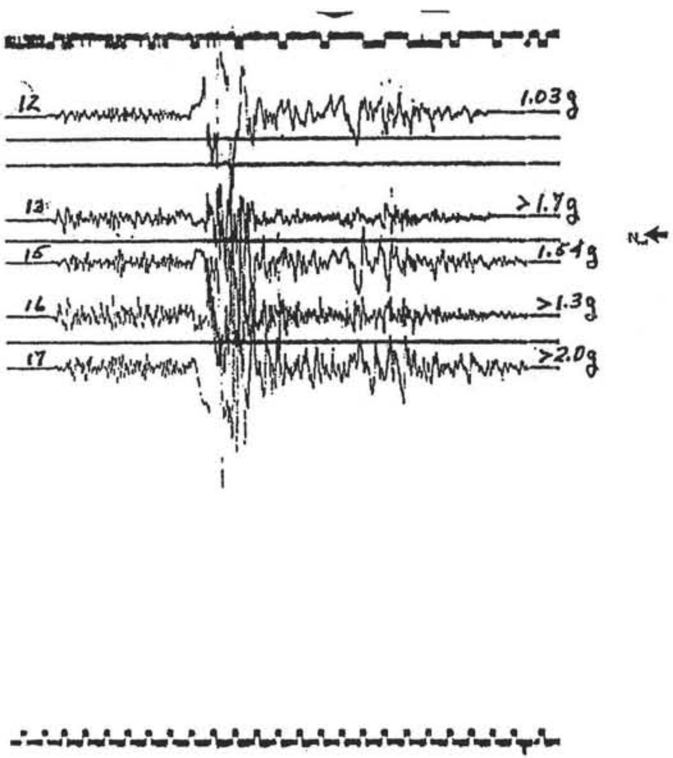
15 Left (South) Abutment: W

16 " Up

17 " N

* R, T = Radial, Transverse to Dam Crest

Fig. 17 Strong motion accelerograms recorded at Pacoima Dam



Pacoima Reservoir - Pacoima Dam
(CSMIP Station No. 24207)

SENSOR LOCATIONS

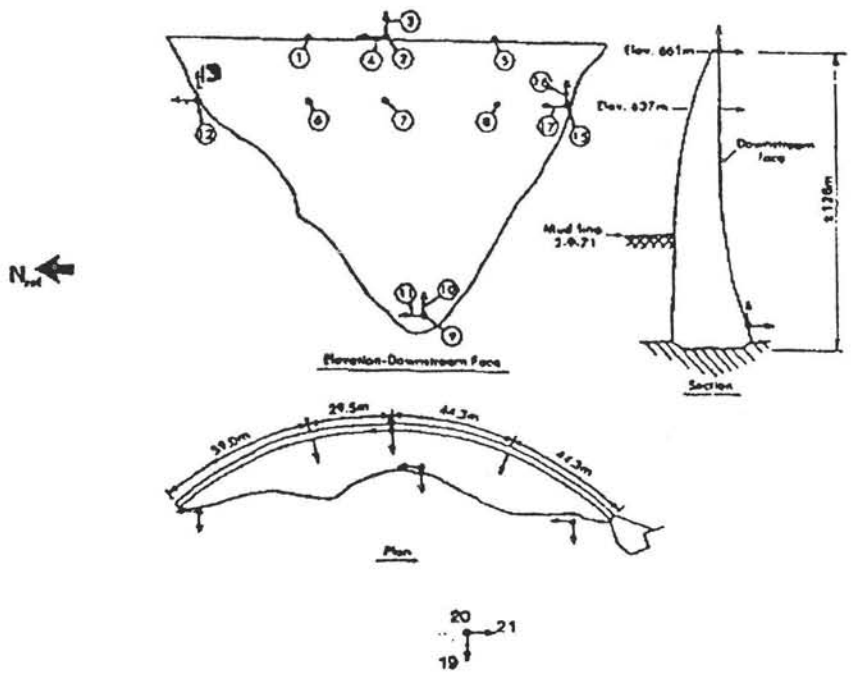


Fig. 18 Strong motion accelerograms recorded at Pacoima Dam (continuation)

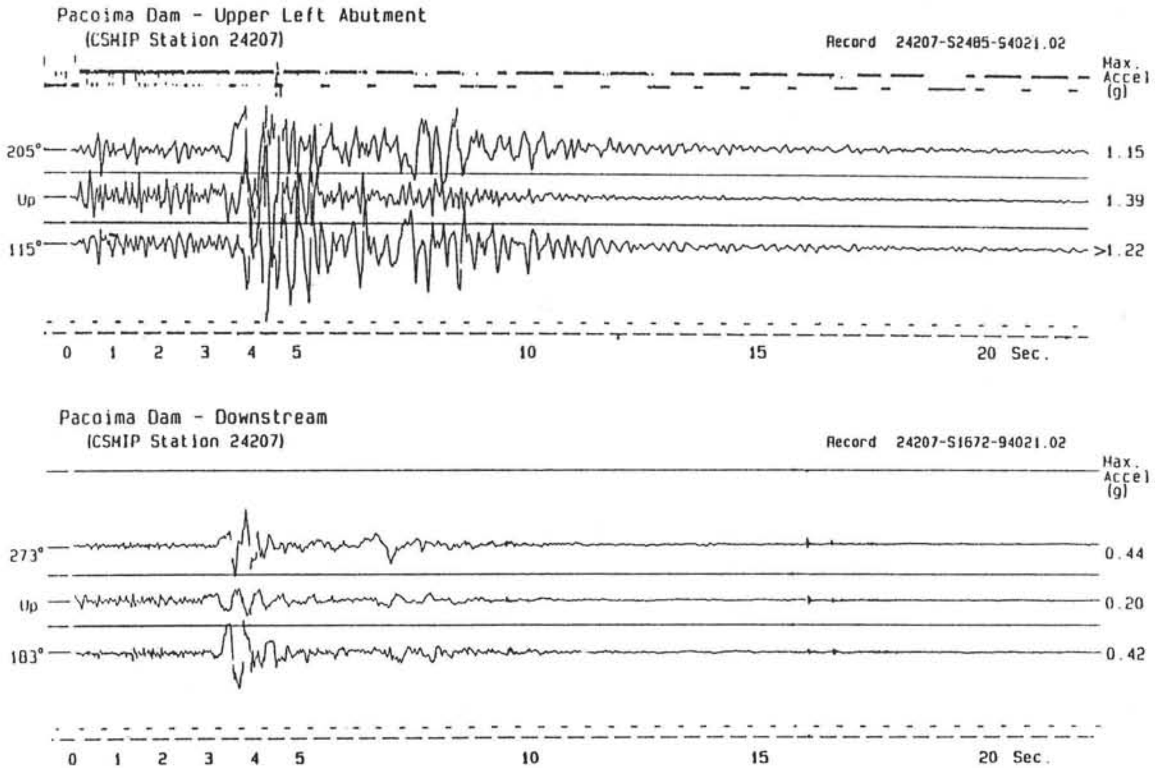


Fig. 19 Strong motion accelerograms recorded at Pacoima Dam (continuation)

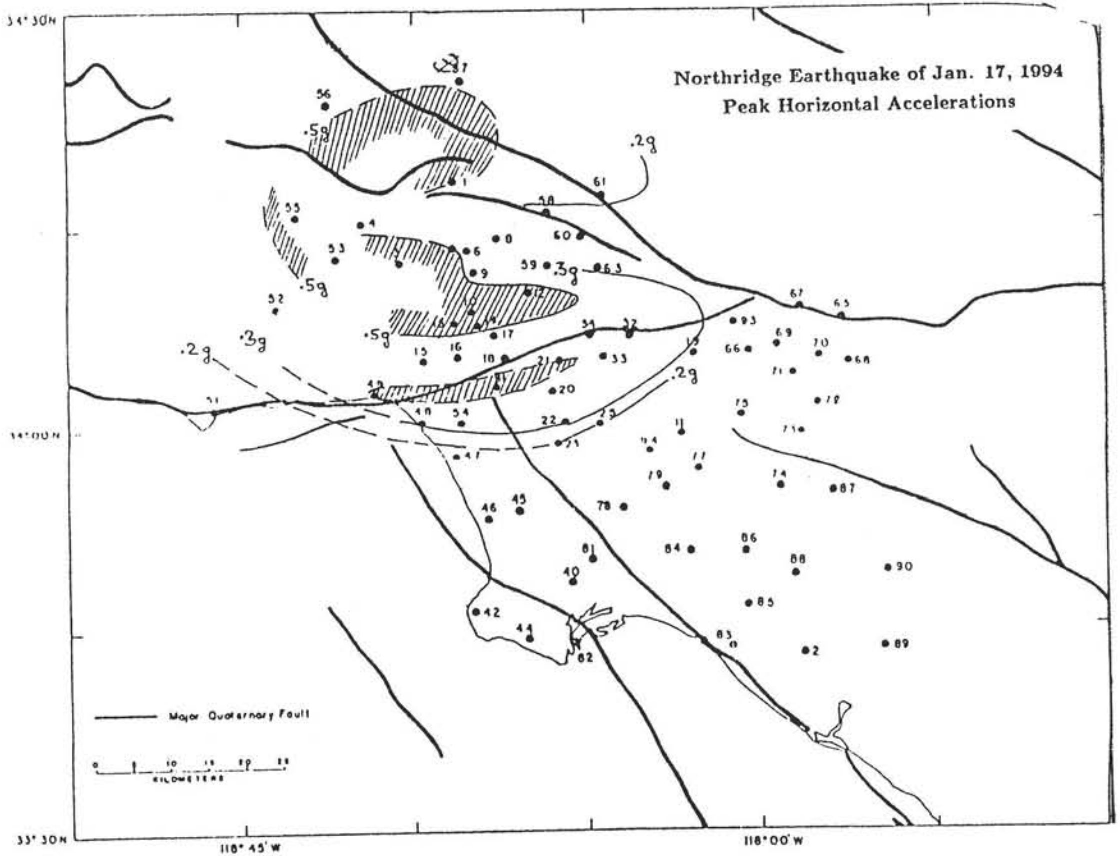


Fig. 20 Distribution of horizontal peak accelerations exceding 0.2g

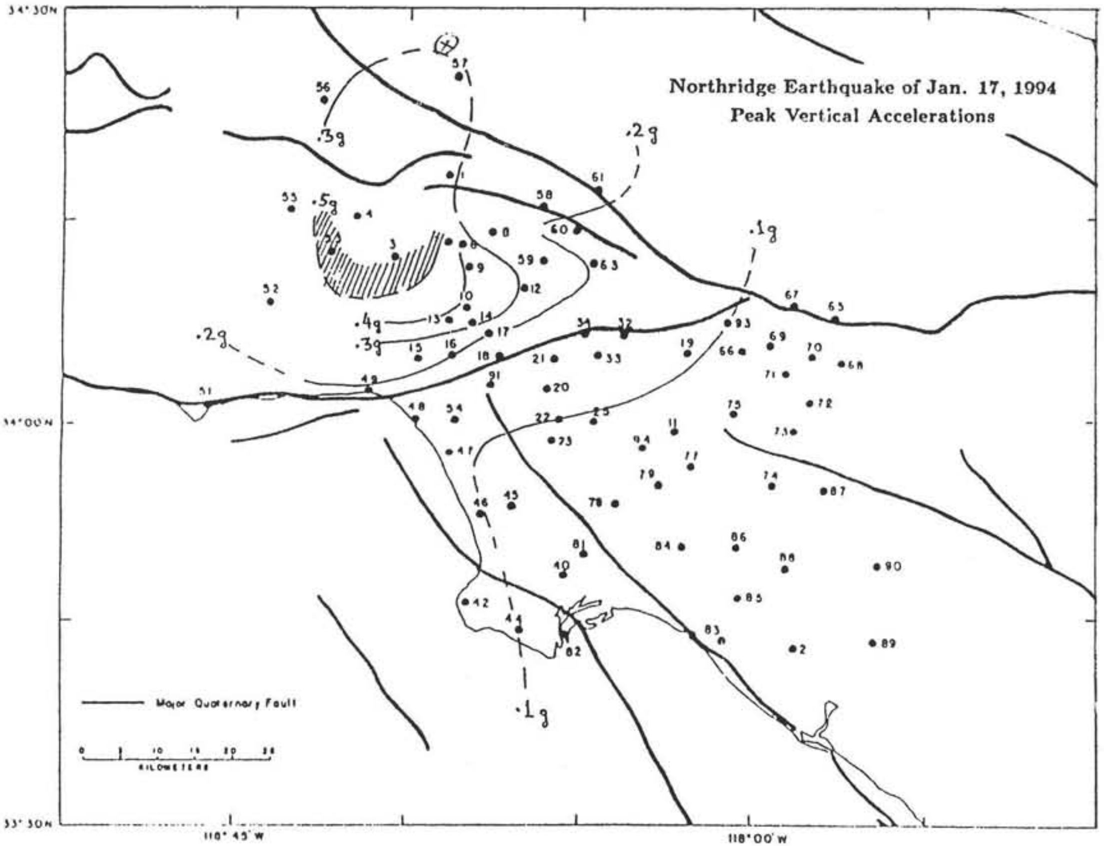


Fig. 21 Distribution of vertical peak accelerations exceding 0.1g

Table 1

Data Recovered From Selected Stations of the California Strong Motion Instrumentation Program (CSMIP) for the 17 January 1994 Northridge/San Fernando Valley Earthquake

No.	Station Name	N. Lat.	W. Long	Epicentral Distance*	Maximum Acceleration Free-Field	Base	Struct.
24386	Van Nuys - 7-story Hotel	34.221	118.471	6 km	—	0.47g H 0.30g V	0.59g H
24436	Tarzana Cedar Hill Nursery	34.160	118.534	7 km	1.82g H 1.18g V	—	—
24087	Arleta - Nordhoff Ave. Fire Station	34.236	118.439	9 km	0.35g H 0.59g V	—	—
24322	Sherman Oaks - 13-story Commercial Bldg.	34.154	118.465	10 km	—	0.46g H 0.18g V	0.90g H
24514	Sylmar - 6-story County Hospital	34.326	118.444	15 km	0.91g H 0.60g V	0.82g H 0.34g V	2.31g H
24088	Pacoima - Kagel Canyon Fire Sta. # 4	34.288	118.375	17 km	0.44g H 0.19g V	—	—
24207	Pacoima Reservoir - Pacoima Dam	34.334	118.396	18 km	0.44g H 0.20g V	0.54g H 0.43g V	> 2.3g H > 1.7g V
24279	Newhall - LA County Fire Station	34.387	118.530	19 km	0.63 g H 0.62g V	—	—
24464	North Hollywood - 20-story Hotel	34.138	118.359	19 km	—	0.33g H 0.15g V	0.66g H
24231	Los Angeles 7-story UCLA Math-Science Bldg.	34.069	118.442	19 km	—	0.29g H 0.25g V	0.77g H
24389	Century City LACC North	34.064	118.417	20 km	0.27g H 0.15g V	—	—
24643	Los Angeles - 19-story Office Bldg.	34.059	118.416	21 km	—	0.32g H 0.13g V	0.65g H
24332	Los Angeles - 3-story Commercial Bldg.	34.058	118.417	21 km	—	0.33g H 0.15g V	0.97g H 0.26g V
24385	Burbank - 10-story Residential Bldg.	34.187	118.311	21 km	—	0.30g H 0.13g V	0.79g H
24370	Burbank - 6-story Commercial Bldg.	34.185	118.308	22 km	—	0.35g H 0.15g V	0.49g H
24670	Los Angeles - 110/405 Interchange Brigde	34.031	118.433	23 km	—	—	1.00g H 1.83g V
24303	Los Angeles - Hollywood Storage Bldg. Free Field	34.090	118.339	23 km	0.41g H 0.19g V	—	—
24236	Los Angeles - Hollywood Storage Bldg.	34.090	118.338	23 km	0.41g H 0.19g V	0.29g H 0.11g V	1.61g H
24538	Santa Monica - City Hall Grounds	34.011	118.490	24 km	0.93g H 0.25g V	—	—
24251	Wood Ranch Reservoir - Main Dam & Dikes	34.240	118.820	26 km	—	—	0.39g H 0.18g V
24157	Los Angeles - Baldwin Hills	34.009	118.361	28 km	0.24g H 0.10g V	—	—
24612	Los Angeles - Pico and Sentous	34.043	118.271	31 km	0.19g H 0.07g V	—	—

* Distance from epicenter at 34.219°N, 118.538°W

Table 1 (continued)

Data Recovered From Selected Stations of the California Strong Motion Instrumentation Program (CSMIP) for the 17 January 1994 Northridge/San Fernando Valley Earthquake

					Maximum Acceleration		
No.	Station Name	N. Lat.	W. Long	Epicentral Distance*	Free-Field	Base	Struct.
24602	Los Angeles - 52-story Office Bldg.	34.051	118.259	32 km	—	0.15g H 0.11g V	0.41g H
24611	Los Angeles - Temple and Hope	34.059	118.246	32 km	0.19g H 0.10g V	—	—
24655	Los Angeles - 6-story Parking Structure	34.021	118.289	32 km	—	0.26g H 0.22g V	1.21g H 0.52g V
24629	Los Angeles - 54-story Office Bldg.	34.048	118.260	32 km	—	0.14g H 0.08g V	0.19g H
24652	Los Angeles - 6-story Office Building	34.021	118.287	32 km	—	0.24g H 0.08g V	0.59g H 0.18g V
24569	Los Angeles - 15-story Govt. Office Bldg.	34.058	118.249	32 km	—	0.21g H 0.07g V	0.29g H
24579	Los Angeles - 9-story Office Bldg.	34.044	118.261	32 km	—	0.18g H 0.12g V	0.34g H
24601	Los Angeles - 17-story Residential Bldg.	34.053	118.248	33 km	—	0.26g H 0.08g V	0.58g H
24283	Moorpark	34.288	118.881	33 km	0.30g H 0.15g V	—	—
14654	El Segundo - 14-story Office Bldg.	33.920	118.390	36 km	—	0.13g H 0.04g V	0.25g H 0.17g V
24605	Los Angeles - 7-story University Hospital (Base Isolated)	34.062	118.198	36 km	0.49g H 0.12g V	0.37g H 0.09g V	0.21g H 0.13g V
24463	Los Angeles - 5-story Warehouse	34.028	118.223	36 km	—	0.26g H 0.08g V	0.29g H
24047	Vasquez Rocks Park	34.492	118.327	36 km	0.16g H 0.09g V	—	—
24541	Pasadena - 6-story Office Building	34.146	118.147	37 km	—	0.17g H 0.09g V	0.21g H
24468	Los Angeles - 8-story CSULA Admin. Bldg.	34.067	118.168	38 km	—	0.17g H 0.06g V	0.25g H 0.17g V
24592	Los Angeles - City Terrace	34.053	118.171	39 km	0.32g H 0.13g V	—	—
24580	Los Angeles - Fire Command Control Bldg. (Base Isolated)	34.053	118.171	39 km	0.32g H 0.13g V	0.22g H 0.11g V	0.35g H 0.30g V
24607	Lake Hughes 12A	34.571	118.560	39 km	0.26g H 0.12g V	—	—
24401	San Marino - Southwestern Academy	34.115	118.130	39 km	0.16g H 0.09g V	—	—
24278	Castaic - Old Ridge Route	34.564	118.642	39 km	0.59g H 0.25g V	—	—
14403	Los Angeles - 116th Street School	33.929	118.260	41 km	0.20g H 0.06g V	—	—

* Distance from epicenter at 34.219°N, 118.538°W

Table 1 (continued)

Data Recovered From Selected Stations of the California Strong Motion Instrumentation Program (CSMIP) for the 17 January 1994 Northridge/San Fernando Valley Earthquake

No.	Station Name	N. Lat.	W. Long	Epicentral Distance*	Maximum Acceleration Free-Field	Base	Struct.
14196	Inglewood - Union Oil Yard	33.905	118.279	42 km	0.12g H 0.06g V	—	—
24272	Lake Hughes # 9	34.608	118.558	43 km	0.24g H 0.09g V	—	—
24399	Mt. Wilson - Caltech Seismic Station	34.224	118.057	44 km	0.23g H 0.11g V	—	—
14368	Downey County Maintenance Bldg.	33.924	118.167	47 km	0.23g H 0.14g V	—	—
14242	Long Beach - Rancho Los Cerritos	33.840	118.194	53 km	0.08g H 0.05g V	—	—
14606	Whittier 8-story Hotel	33.975	118.036	54 km	—	0.19g H 0.10g V	0.49g H
14406	Los Angeles - Vincent Thomas Bridge	33.750	118.271	58 km	—	0.25g H 0.08g V	0.65g H 0.44g V
14560	Long Beach - City Hall Grounds	33.768	118.196	59 km	0.06g H 0.03g V	—	—
14533	Long Beach - 15-story Govt. Office Bldg.	33.768	118.195	59 km	0.06g H 0.03g V	0.04g H 0.03g V	0.06g H 0.05g V
23595	Littlerock - Brainard Canyon	34.486	117.980	59 km	0.07g H 0.04g V	—	—
24609	Lancaster 5-story Hospital	34.688	118.158	63 km	—	0.07g H 0.04g V	0.28g H
14578	Seal Beach - 8-story Office Bldg. (Base Isolated)	33.757	118.084	66 km	0.09g H 0.04g V	0.08g H 0.03g V	0.15g H 0.16g V
23247	Big Dalton Reservoir - Big Dalton Dam	34.170	117.808	68 km	—	—	0.18g H 0.04g V
23590	Wrightwood - Jackson Flat	34.381	117.737	76 km	0.06g H 0.03g V	—	—
23574	Wrightwood - Swarhout Valley	34.369	117.658	83 km	0.06g H 0.04g V	—	—
23598	Rancho Cucamonga Deer Canyon	34.169	117.579	89 km	0.07g H 0.03g V	—	—
23497	Rancho Cucamonga Law and Justice Center (Base Isolated)	34.104	117.574	90 km	0.08g H 0.03g V	0.05g H 0.03g V	0.10g H 0.03g V
23650	Devore - 115/215 Interchange Brigde	34.225	117.409	104 km	—	—	0.24g H 0.05g V
23634	San Bernardino - 5-story Hospital	34.132	117.321	113 km	—	0.06g H 0.03g V	0.24g H
23622	San Bernardino - 1-story Commercial Bldg.	34.098	117.293	116 km	—	0.05g H 0.02g V	0.15g H

* Distance from epicenter at 34.219°N, 118.538°W

Table 1 (continued)

Data Recovered From Selected Stations of the California Strong Motion Instrumentation Program (CSMIP) for the 17 January 1994 Northridge/San Fernando Valley Earthquake

					Maximum Acceleration		
				Epicentral	Free-Field	Base	Struct.
No.	Station Name	N. Lat.	W. Long	Distance*			
23542	San Bernardino - E & Hospitality	34.065	117.292	116 km	0.10g H 0.04g V	—	—
23631	San Bernardino - 110/215 Interchange	34.064	117.296	116 km	0.10g H 0.04g V	0.13g H 0.04g V	0.47g H 0.31g V
12649	Beaumont - 110/60 Interchange Bridge	33.933	116.990	146 km	—	—	0.09g H 0.03g V
12636	Sage - Fire Station	33.580	116.931	165 km	0.03g H 0.02g V	—	—
12666	North Palm Springs 110/62 Interchange Bridge	33.915	116.608	181 km	—	—	0.11g H 0.02g V

* Distance from epicenter at 34.219°N, 118.538°W

PART B. ENGINEERING ASPECTS ON THE JANUARY 17, 1994 NORTHRIDGE EARTHQUAKE

1. LIFELINE DAMAGE

Lifelines are complex systems which distribute resources, transport people and send information. The water supply, water treatment and sewage, electric power supply, communications, transportation of people and of combustible materials (liquids and gases) are examples of lifelines. Although at present only some components of lifelines are explicitly designed to resist earthquakes, the engineering practice of such systems has been improving since lifeline behavior is starting to be considered important in seismic design, in emergency planning, and in the recovery after an earthquake. Current experience always shows that when a large earthquake occurs, there is considerably amount of lifeline damage.

Distinctly from buildings, lifelines are generally parts of networks which may extend over several kilometers. Therefore, they can pass through zones with different types of soils or rock. Lifelines are interdependent systems, which means that damage in one of them influences the behavior of the others. For example, damage or disruption of the electric power supply can affect the operation of water pumping, thus limiting the available amount of water; moreover, in order to repair the electric power system, a redundant transportation system is necessary.

During the Northridge earthquake, most lifelines showed adequate redundancy; therefore, large service interruptions were avoided. The transportation system was the exception.

1.1 Water Supply System

According to local government information, three days after the earthquake (January 20), 36,000 people suffered from shortage of water supply. By January 25, only 2,000 persons lack of water supply due to the work of 50 crews. Most of the pipeline fractures occurred near the epicentral zone.

1.2 Gas Distribution System

Although there are not statistics on damages, it has been estimated that damages in the gas distribution system will be less than those in the water supply network. One day after the earthquake, about 15,000 to 20,000 customers lost gas supply. By Friday 21, the number of affected customers increased to 40,000. One of the most important fires after the earthquake occurred in Granada Hills, a residential zone north to the epicenter. Here, a gas leak from a 60–cm diameter main parallel to a water pipe, caused the explosion. Several wooden houses were burnt mainly because of water shortage for extinguishing the fire.

1.3 Electric Power System

After the earthquake, 150,000 customers had no service; but by January 21 only 2,300 customers remained without electricity. Damage was concentrated in one 500kV substation and in two 230kV substations from the Sylmar Power Station (Fig. 22), NW to the epicenter. This power station was also damaged in the 1971 San Fernando earthquake. At that time, this damage showed the need to fix the electrical equipment with adequate anchorages. In fact, at that time, because of anchorage deficiencies, several transformers and other components were turned over and failed causing severe damage. As a result, components and equipment were replaced by new ones designed to resist a 0.5g acceleration level and also fixed with adequate anchorages. Nevertheless, during the Northridge earthquake, instruments in one of the substations registered ground accelerations of 0.6g. Several electric components were again severely damaged.

The ceramic components are one of the most vulnerable parts to earthquakes actions, particularly in 220kV equipments or bigger. While the development of high-strength ceramic or of isolators with a more ductile materials is done, isolation systems must be designed for low stress levels. Other option is to replace the cantilever supports for the isolators with multiple supports. The use of dampers has shown to be adequate.

1.4 Communication System

Moderate damage was suffered by the equipment of telephone central stations. Some of these centrals went out of service due to the interruption of the electric power supply and the failure of emergency plants. Some phone circuits were overloaded after the earthquake. The low level of damage contrasts with that observed after the 1971 San Fernando earthquake. At that time, some switch boxes overturned since they were not laterally braced. Failures observed in 1971 forced telephone companies to develop minimum requirements for buildings and bracing systems.

1.5 Transportation System

During the 1971 San Fernando earthquake, the road and bridge system near Los Angeles was considerably damaged. Five freeway bridges collapsed and 42 more had various different levels of damage. In the aftermath of this experience, a complete revision of the seismic design criteria for bridges was carried out. According to the old criteria, a base shear coefficient equal to 0.06 was assumed. This value had been used since 1943. After the revision, published in 1974, seismic forces were obtained as a function of the maximum possible acceleration on rock, of the soil profile, and of the ductility level, and risk of the structural system. Base shear coefficient was increased approximately to 0.1. Since that time, design standards for bridges have not been considerably improved. Because of the damage reported in 1971, the California Transportation Department has incorporated the use of dynamic analysis and of results from research for designing bridges.

Almost the entire 1,000 km of freeways in Los Angeles area resisted the 1994 earthquake without considerable damages. As a reference, three million cars move everyday in this area. In most cases, rehabilitated structures (steel jacketing of columns (Fig. 23)) by Caltrans since the Loma Prieta earthquake (1989) behaved well (Fig. 24). Nevertheless, damage in 10 bridges was observed (Figs. 25 to 27). Main damage occurred in Interstate Highway 5 (at the junction with Roads 118 and 210), in Interstate Highway 405 and I-10; and in Roads 101 and 118. Three types of failures were observed: a) Column failure due to shear-compression (Figs. 26 and 27); b) Column flexural hinging (Fig. 28); and c) Beams fell down because they lost their seats.

The junction of the I-5 with R-14 was under construction when the San Fernando earthquake occurred; at that time, the structure partially collapsed and showed damage in other parts. This same junction collapsed in the Northridge earthquake, possibly due to shear failure of columns. These columns have a small height to depth ratio. This feature increased the stiffness and, consequently, augmented the magnitude of the lateral force in this element. Other junction which suffered damage in both earthquakes, 1971 and 1994, was that of R-5 with R-210.

The most common failure mode was brittle shear or semiductile shear (flexural hinging first and shear failure after). For example, in I-10 near La Cienega, concrete columns showed an inclined failure plane and concrete crushing in the zone where longitudinal reinforcement buckled (Fig. 29). Possibly, high horizontal accelerations caused the column to fail in shear while the vertical acceleration added to the deterioration. According to Caltrans, the I-10 bridges had been identified as highly vulnerable structures and there were to be rehabilitated soon.

Some bridges, which had been rehabilitated with restrainers (cables) to limit excessive longitudinal displacements, collapsed after the beams lost their seats.

Other type of failure was pounding of structures, especially in skewed bridges, where in–plan column distribution generated important torsional effects. In-plan rotations produced large displacements and forces at the end of members sometimes causing the fracture of restrainers used to limit displacements. In some cases, site effects may have increased the ground motion; that is the case of I-10 (located in La Cienega, at 23 kilometers from the epicenter), founded on soft soil. Topographic conditions of this canyon, where the R-5 and R-15 junction is located, might have affected the ground motion.

2. HOSPITAL DAMAGE

Among the emergency group of buildings and installations are hospitals, police and fire stations, civil protection units, rescue units, etc. Obviously, hospitals are buildings which must remain without significant damage to attend injured victims. Modern building codes, like the Mexico City Building Code (RDF87), consider a larger safety factor for this type of structure.

Thus, in RDF-87, design forces are increased by 50%, while in the actual Uniform Building Code adopted in the State of California, design forces are increased by 25%.

In the case of Northridge earthquake, nine hospitals were damaged and were closed temporally. By January 21, only three hospitals remained closed.

One of the damaged hospitals was the Santa Monica Hospital which is a R/C building with concrete structural walls perpendicular to the street, and with frames (beams and columns) parallel to the street (Fig. 30). During the reconnaissance evaluation, the entrance to the building was restricted. Damage was concentrated in the concrete walls and coupling beams (Figs. 31 and 32). Diagonal cracks were observed in R/C walls, which are evidence of high lateral forces. Horizontal cracks were also noted and agree with the location of construction joints. The latter type of cracking occurs along inadequately prepared joints between two castings. Indeed, construction joints must be carefully prepared removing the dust, slag or any other material which can impair bond between the old and new concrete. Construction joints must be roughened to increase the coefficient of friction; vertical rebars must pass through the joint to prevent and control possible cracking. In some cases, problems in construction joints can be explained by deficiencies in the detailing by the structural designer. Regarding coupling beams, tests carried out in laboratories and recent experiences during earthquakes have demonstrate that this type of beams can be detailed relatively easy (by placing diagonal reinforcement); beams designed accordingly have shown excellent response without severe damage. The coupling beams in this building were designed before the knowledge in this field was developed.

Other severely damaged structure was the St. John's Hospital located in Santa Monica. This is a 6-story R/C building with an appendix; possibly, the structure was built 40 years ago. Only the second story at the north facade suffered damage. Columns and short walls showed large diagonal cracks. Damaged was caused by a drastic change in strength and stiffness in this story with respect to others (Fig. 33).

The Olive View Medical Center (identified as Sylmar Hospital) is a 6-story building plus a basement (Fig. 34). It has a central core of R/C walls and a ductile moment-resisting space steel frame. The ground and first floors have a square plan while the remainder of the building has a cruciform plan. At the end of the cross arms there are structural walls made with steel plates. The foundation consists of R/C walls and slab. The structure is located in an alluvial plain, 15 kilometers away from the epicenter. The floor system was built using steel decks covered with concrete. Beam spans are 6.5 m and story height is 5.4 m. This hospital substitutes the hospital building that collapsed during the 1971 San Fernando earthquake. In this building, structural walls in the upper stories were interrupted at the ground story. This situation caused the collapse of exterior stairs and tilting of the building. Damage in ground floor columns, particularly in corner columns, showed the inadequate detailing of these elements with small diameter hoops with large spacing. The maximum estimated horizontal acceleration in the 1971 earthquake was 0.5g. The actual hospital, with 350 beds, was built in 1975, and it was not occupied until 1985, after satisfying the strict requirements for safety and hygiene of California. During the reconnaissance, the only structural damage observed were diagonal cracks in the basement walls (box foundation) which were 0.3 mm width and were spaced at almost 20 cm. Basement columns are R/C elements with a square transverse section with 50 cm sides. These columns were harmless.

Maximum recorded horizontal accelerations at the base of the building (inside the foundation) were 0.82g while in the roof level increased to 2.31g. In free field, maximum recorded horizontal and vertical accelerations were 0.91g and 0.60g, respectively. It is important to note that a high level of design base accelerations for hospitals is about 0.3g.

In the basement, office files with patient information overturned and some ceiling panels fell (Fig. 35). The upper most two stories were flooded due to a fracture of 2.5-cm diameter copper pipes. Also, seven fractures of the black iron pipe of the fire sprinkler system were identified. Although there was no structural damage, the water damage obligated the hospital evacuation.

At the roof of the building, horizontal measured accelerations during the earthquake were 2.31g. A lamp detachment was observed. An air extractor equipment slipped due to an inadequate detail in the anchorage supports (Fig. 36). Anchor bolts were cut just above the nut. Shaking caused by the earthquake caused ripping of the bolt's thread thus allowing displacement of the equipment. Similar incipient failures in other equipments with the same anchoring detail were observed.

Other damaged hospital was the Indian Hills Medical Center. This structure had suffered damage during San Fernando earthquake. At that time, four R/C structural walls showed many diagonal cracks. The structure was rehabilitated by epoxy resin injection and by increasing the wall thickness. During the Northridge earthquake the building showed damage in the structural walls, particularly crushing and failure of longitudinal steel overlaps at the fourth level.

3. DAMAGE IN BUILDINGS

As a result of this earthquake, only a small percentage from the total economic loss is attributed to structural damage. Damage in non-structural elements and installations led to important direct and indirect economic losses. The latter is due to disruption of business operations. Building damage was distributed over a large area, although the most affected zones were Northridge, Canoga Park, Hollywood and Santa Monica. As it was mentioned before, in La Cienega District, in Santa Monica, it is probable that local soil conditions might have amplified the ground motion.

3.1 Dwellings

It is commonly accepted that wood is a good material to be used in seismic areas.

Most dwellings in the epicentral zone were one-story timber houses and timber apartment complexes. In general, wood has a ductile behavior when compressed, while under tension (in particular in the orthogonal direction to the grain) its behavior is brittle. Against the belief of such good performance, earthquakes have shown the vulnerability of structures with different anchoring systems and with ground floors with large open spaces used as parking. It is interesting to mention that several structures with these features collapsed during the 1971 San Fernando and the 1989 Loma Prieta earthquakes. The Northridge event was not the exception.

The structural system in American housings is similar and is made of a basic timber frame which is used several times in a house. Loads and spans are small. Some buildings have relatively heavy unreinforced masonry chimneys; some structures are often covered, partially or totally, with a facade finishing. In a well designed and detailed structure, lateral loads are transferred from floor diaphragms to structural walls. Structural walls are walls covered with stucco or plywood (if they are exterior elements) or with a gypsum board (if they are interior walls).

Preliminary estimates give a toll of 15,000 damaged houses; most of them with non-structural distress. In this number, the collapses of reinforced and unreinforced masonry chimneys (with a replacement cost which varies between 5,000 and 10,000 dollars) and roof damage are included. Masonry fences were also damaged; some collapses (overturning) were recorded.

A characteristic of the damage pattern produced by the Northridge earthquake was that observed in multi-story timber frame structures. Several of them were lacking of wood structural walls. The collapse of the Northridge Meadow Apartments complex caused 16 fatalities. The structural characteristics of such type of buildings are similar: they are two- or three- story wood buildings with a ground soft story used as parking (Fig. 37). These apartment buildings were designed and constructed prior to the 1975 recommendations which required structural walls to be made with plywood sheets nailed to the frame (Fig. 38). During the earthquake, large lateral displacements were concentrated in the ground soft story (Fig. 39). In some instances, the structure was left standing but severely damaged; other buildings collapsed over the soft story. In other cases, failure was observed along the joints between the concrete masonry foundation (reinforced masonry) and the timber structure, and between upper wooden stories.

3.2 Masonry Buildings

Main causes of damage and collapse of masonry structures in past quakes in different parts of the world have been: 1) lack of anchorage of roof or floor beams to walls; 2) inadequate detailing of beam-to-wall anchorages; 3) out-of-plane wall flexural failure; 4) diagonal cracking of the masonry panels; 5) excessive distortion of floor diaphragms; and 6) deficiencies in the shear transfer mechanism between floor diaphragms and walls. All these types of damage were observed in the area affected by the Northridge earthquake (Figs. 40 to 42).

In 1981, Los Angeles County started a rehabilitation program of unreinforced masonry buildings. Most of this type of structures, built at the beginning of the century, have flexible wooden floor system, generally not anchored to the walls. Multi-story buildings possess R/C slabs supported on walls. Rehabilitation techniques have included stiffening of roof and floors and bolting them to walls (Fig. 43). Most rehabilitated structures withstood the 1994 event, although in few cases severe damage was recorded. Buildings not retrofitted experienced large diagonal cracking, out-of-plane collapses and considerable brick crushing.

Based on this experience, it is clear that the rehabilitation program has not been completely effective; however, it did contribute to reduce this type of structure's vulnerability.

3.3 Reinforced Concrete Buildings

A separate section is devoted to parking structures due to their outstanding damage rate.

Observed failure modes in R/C structures included: 1) diagonal cracking and concrete crushing in poorly detailed beam-column joints; 2) shear failure at beam and column ends with improper detailing; 3) bond and anchorage failures of steel reinforcement (Figs. 44 and 45); 4) shear failure of coupling beams (Fig. 46); and 5) shear failure (brittle) in short ("captive") columns with height-to-width aspect ratios of 2.5 or less (Figs. 47 and 48).

The instrumented building located closest to the epicenter (7 km) is a R/C frame built in the 60's and damaged in the 1971 event (Fig. 49). In the Northridge earthquake the structure was subjected to a base acceleration equal to 0.47 g; a 0.59 g maximum acceleration was recorded at the roof. Maximum recorded vertical acceleration was 0.30 g which occurred before the horizontal maximum (this was the case for all records). Although this building is not greatly damaged, its demolition is probable.

Tilt-up construction, used for industrial buildings and warehouses, has behaved poorly during earthquakes. In such type of structures, floor diaphragms are made either of wood or metal. During the 1994 event, failures were located at the wall-roof connection. The collapse of one tilt-up building was reported; in this structure the roof bolts were ripped off from the walls.

It was reported that the Los Angeles Coliseum suffered considerable, but repairable, damage along a joint between two portions of the structure.

3.4 Parking Structures

Parking structures was the most damaged type of building designed according to present requirements and criteria. Most parking structures in the US have typical spans of 16 to 20 m, to give ample freedom for selecting the layout of car spaces. Since the design is often controlled by the spans to be bridged, precast prestressed elements or cast-in-place post-tensioned members are used. Parking structures located in seismic zones require laterally rigid structural systems to control displacement and, simultaneously, flexible systems to reduce possible distresses caused y volumetric changes of the concrete (shrinkage, creep, etc.).

For short-span parking structures, flat plate and flat slabs are the most typical system. For long spans, two systems are used. For cast-in-place structures, beams and one-way slabs, both post-tensioned, are employed. If precast elements are used, double-tee beams (60 to 80 cm deep) are common. A 5- to 10-cm thick concrete topping is cast on the beams as a riding surface; the topping is also intended to contribute to the diaphragm action of the floor system. Diaphragm action is essential for resisting and transferring horizontal forces to the vertical elements. Thus, diaphragm action is smaller for simple supported beams bearing on corbels than for beams cast monolithically to columns.

For resisting the forces induced by the earthquake, R/C frames and structural walls are commonly used. A peculiar feature of this type of structures are the vehicle ramps. These form a vertical truss which braces the structure. Torsional movements may be induced in the building if the ramp is continuous.

Half-dozen of parking structures failed. Seemingly, failures were due to low redundancy and high flexibility of the lateral load resisting system. These buildings were designed to carry the gravity loads through interior columns which were not detailed to withstand cycling to large displacements (stirrup spacing was large, and in some cases, they were terminated in 90-deg. bends). In general, lateral load resisting system is placed around the perimeter of the building and is made of either ductile frames or ductile structural walls. Due to lateral displacement compatibility, assuming rigid diaphragms, interior columns were pushed to displacements that caused hinging at their ends. The combination of both non-ductile details and large horizontal and vertical accelerations explain the failure of the gravity load carrying system and the consequent structure collapse (Figs. 50 to 53). In some buildings, failure of short columns between ramps was recorded (Fig. 47).

All damaged parking structures did not have integrity reinforcement.

3.5 Steel Buildings

At the time of the reconnaissance reported herein, damage in non-structural components was the only type of distress reported. A number of curtain wall damages and fracture of interior water lines were reported. Water damage occurred in computer equipment, documents, archives, etc.

Failures in welded flange-bolted web moment connections were observed in privately-owned buildings (the reconnaissance team learned about this problem after its return to Mexico). It has been reported in the literature that this detail may not provide satisfactory performance when used for beams in which the web accounts for a substantial portion of the beam's flexural strength. This observation has been attributed to the bolted web connection's limited ability to transfer bending moment, resulting in excessive demands on the beam-flange connections.

4. FINAL COMMENTS

The Northridge earthquake can be considered as a design level quake due to the magnitude of recorded accelerations. The vulnerability of buildings and bridges designed according to present code criteria can be assessed based on their performance. Given the similarities between the Mexico City Building Code and US codes, it is evident that Mexican engineers should be aware of research results.

Failures observed in this quake have pointed again the need for improving our design, detailing and construction practices. The good performance of some structures emphasize the idea of having simple codes whose requirements are applied rather than developing highly sophisticated codes which are not complied with.

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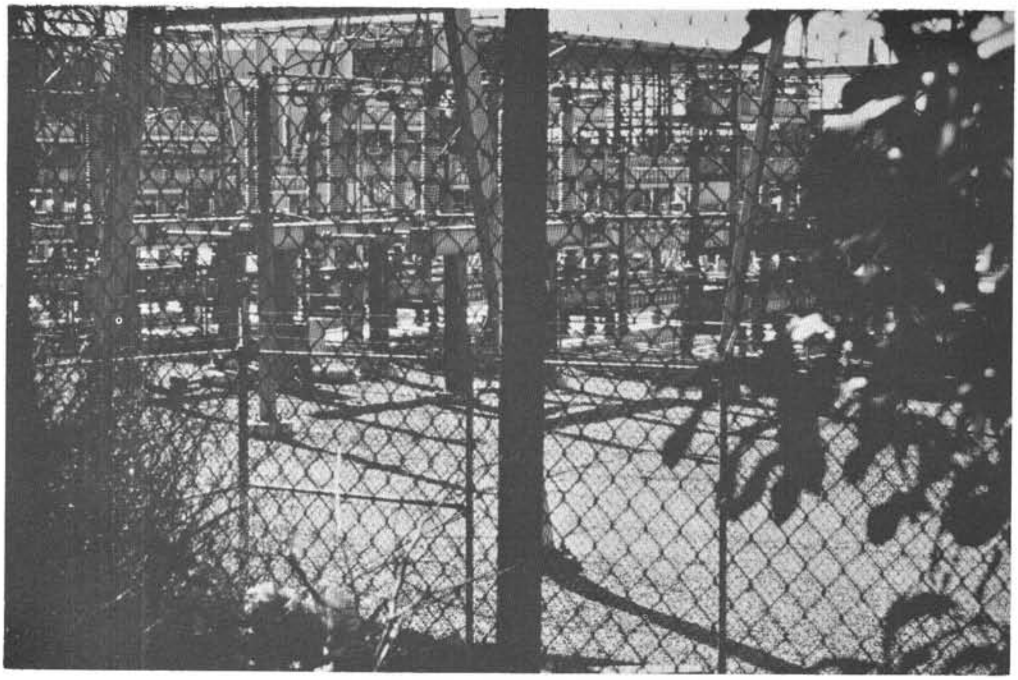

Fig. 22 Sylmar Power Station at the NW part of the epicenter.

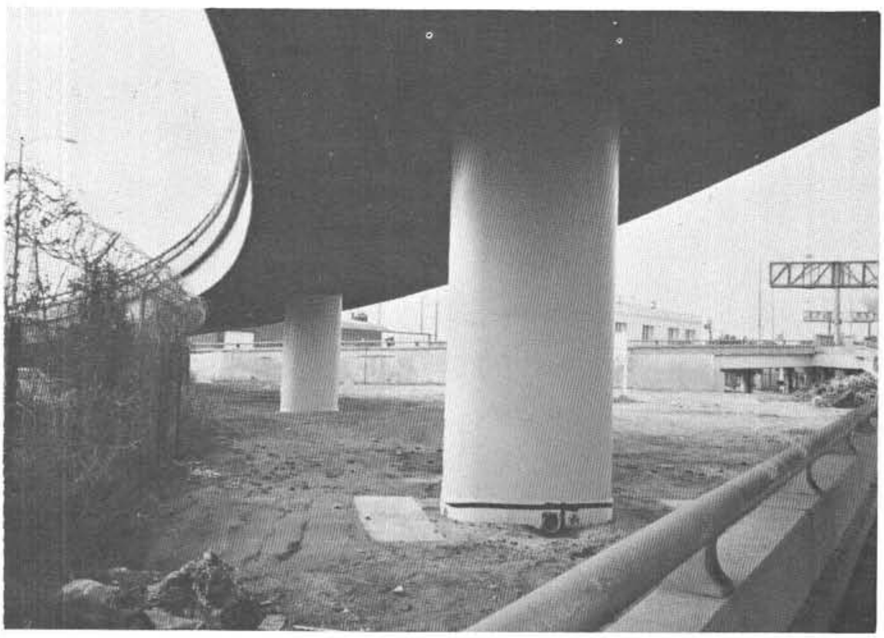

Fig. 23 Steel jacketing of bridge columns behaved well.

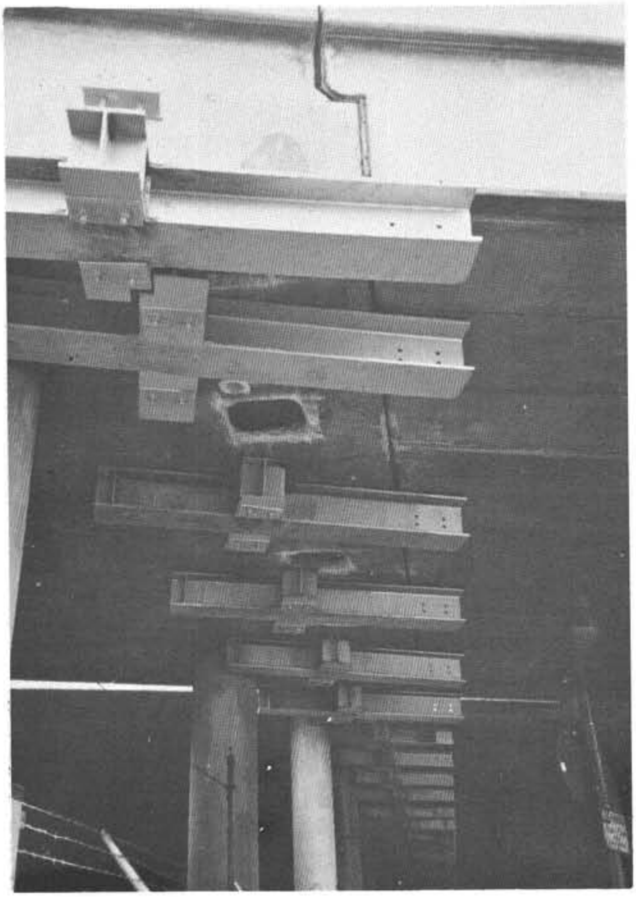

Fig. 24 Rehabilitation of seats by means of increasing the support length with steel members.

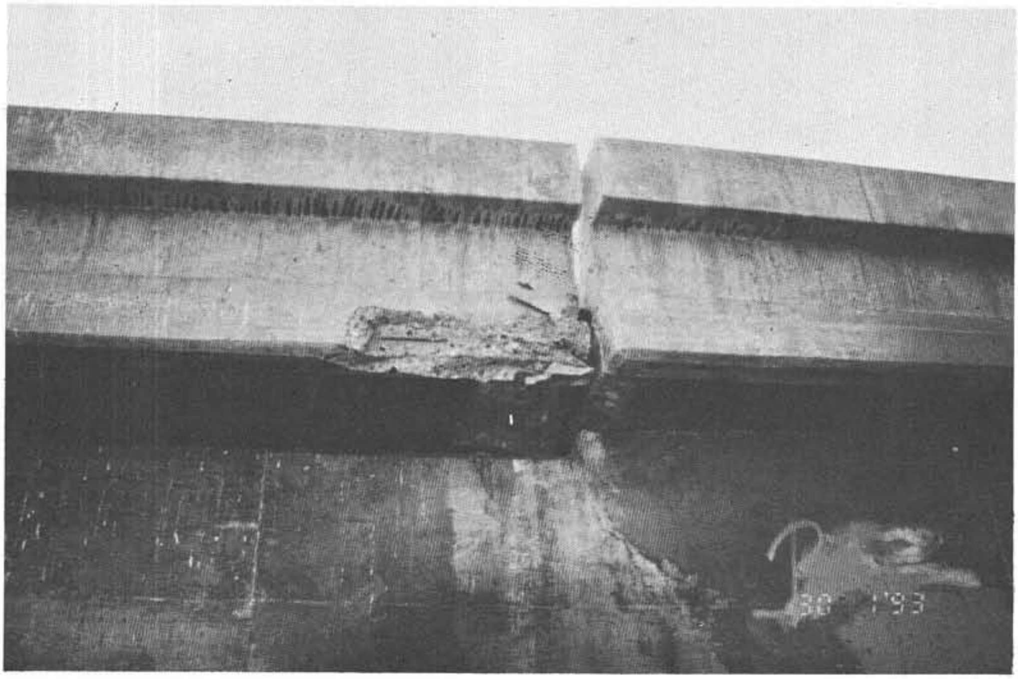

Fig. 25 Spalling of concrete cover in the parapet joint between two precast bridges.

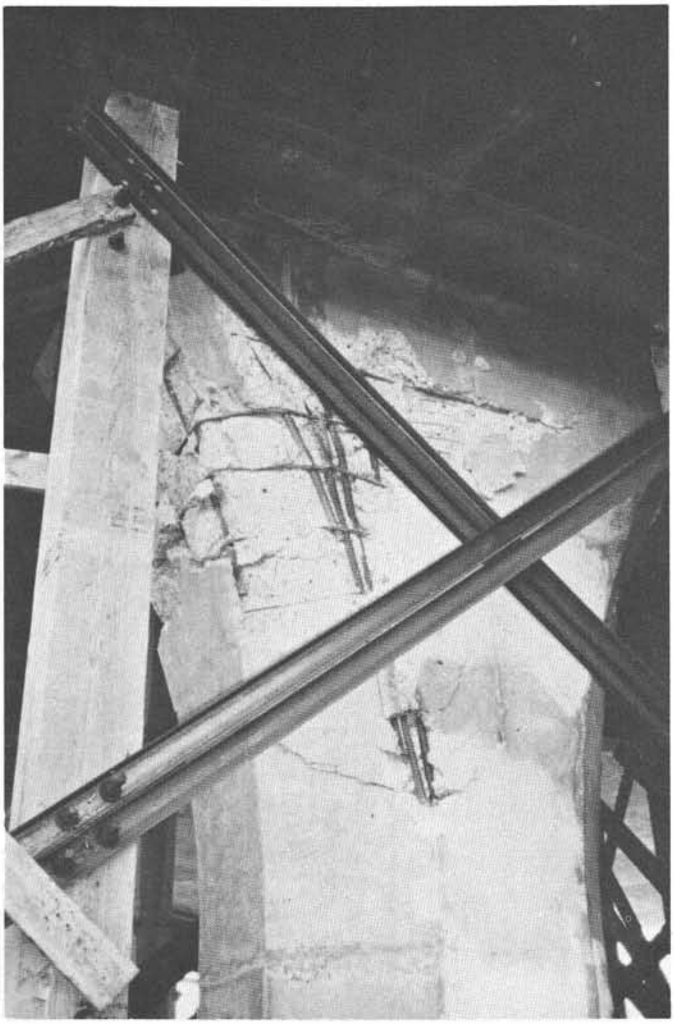

Fig. 26 Shear compression failure and rebar buckling in bridge columns.

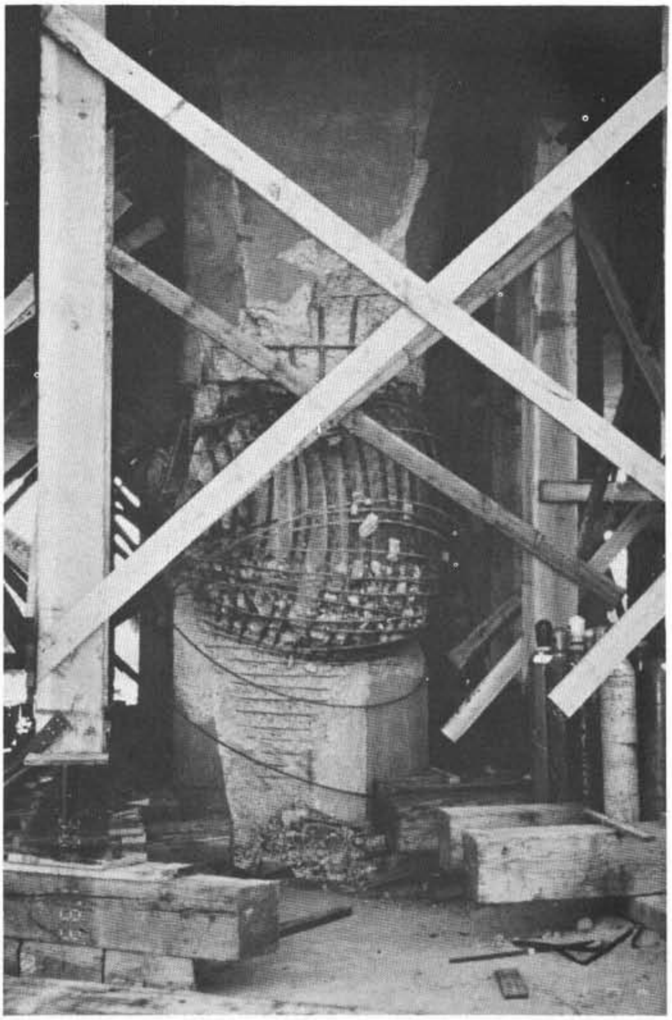

Fig. 27 Shear compression failure and rebar buckling in bridge columns.

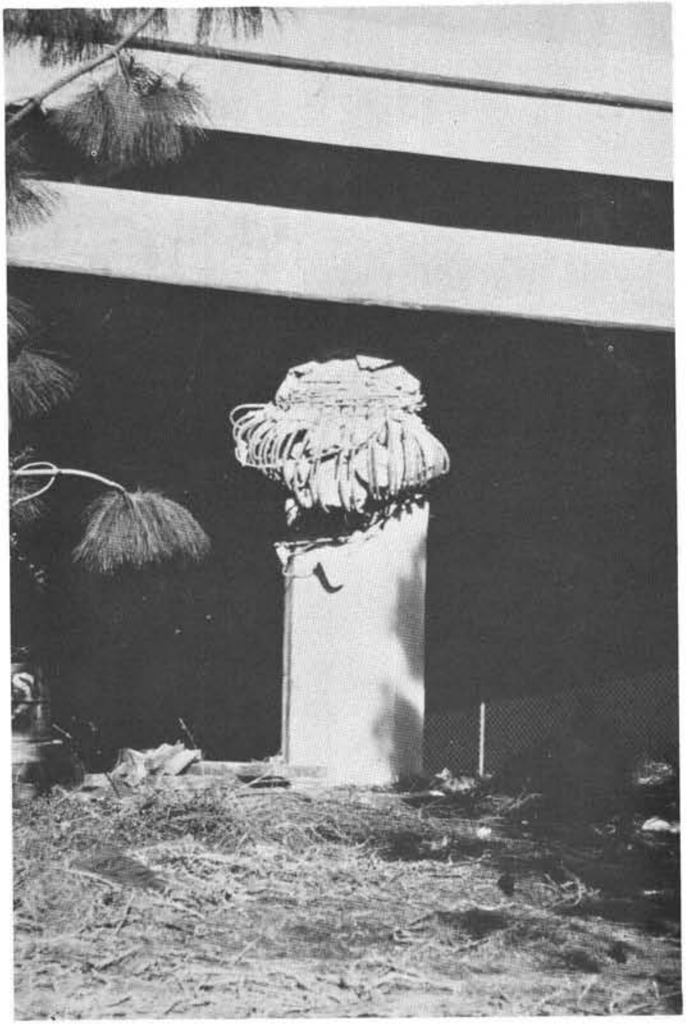

Fig. 28   Column flexural hinging.

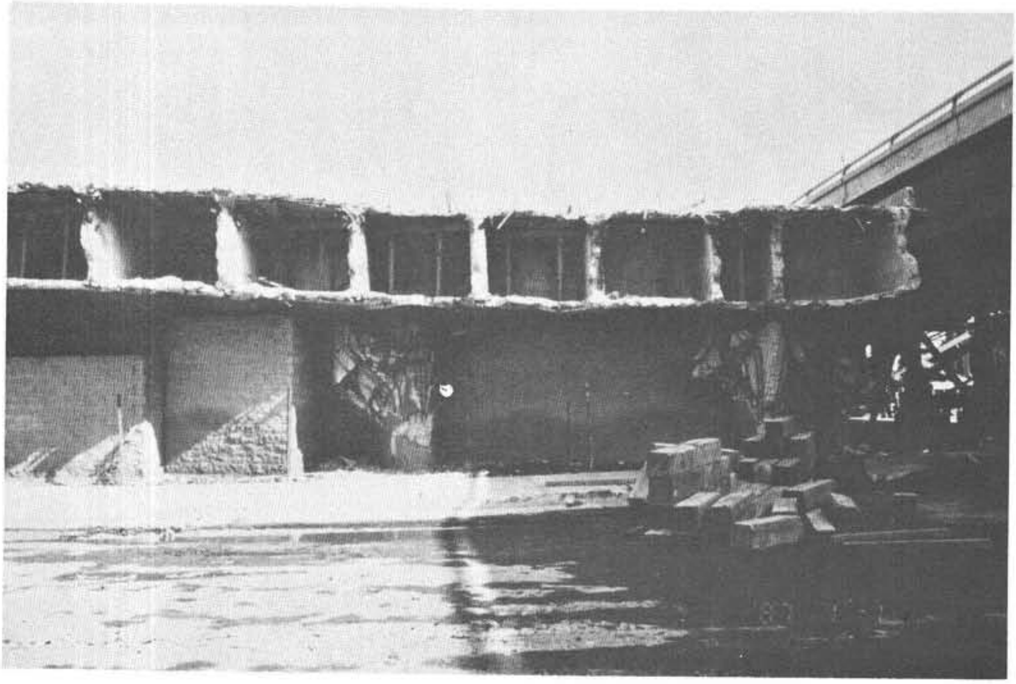

Fig. 29 Impressive buckling of steel bars and concrete crushing along the height.

Fig. 30 General view of the Santa Monica Hospital.

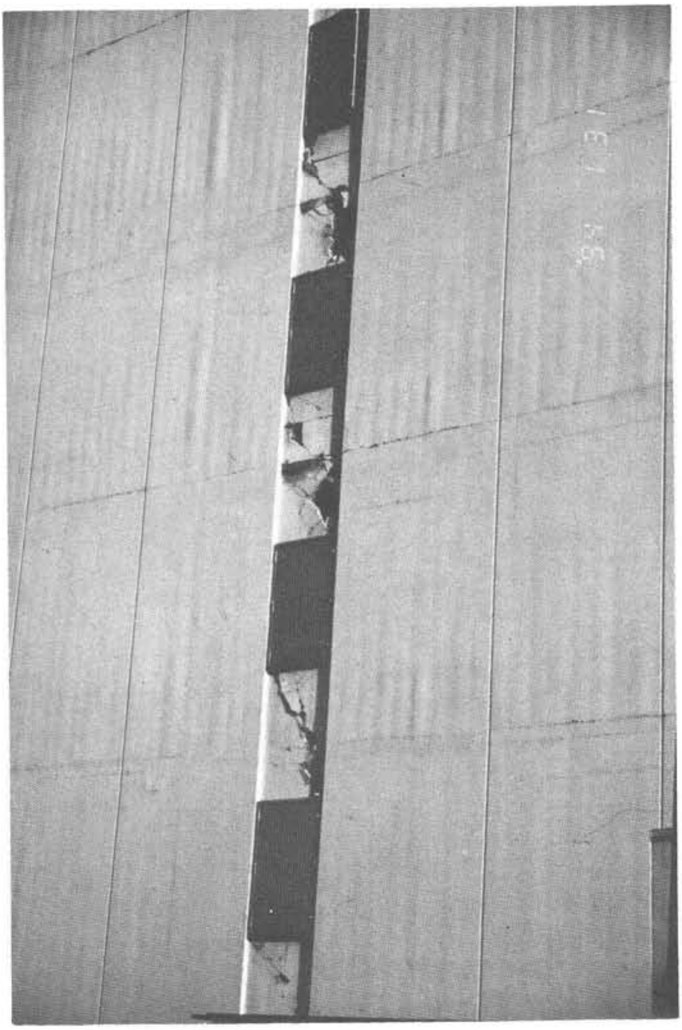

Fig. 31 Detail of shear damage in coupling beams.

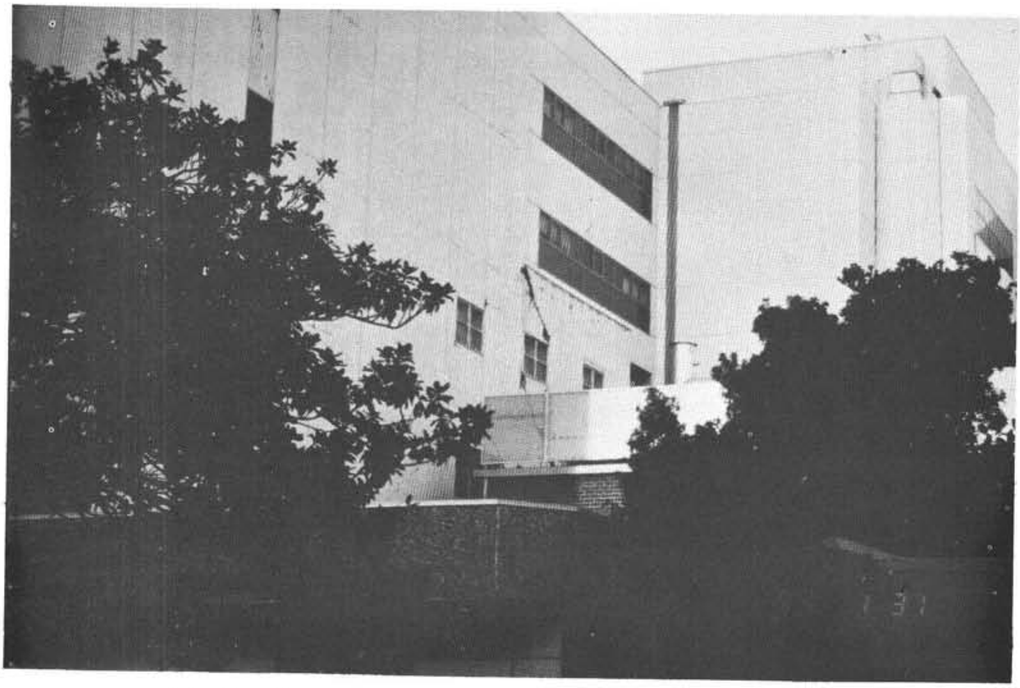

Fig. 32 Shear cracks in concrete walls near window openings.

Fig. 33 Shear cracking in columns and wall piers at the second floor in St. John's Hospital.

Fig. 34 General view of the Olive View Medical Center.

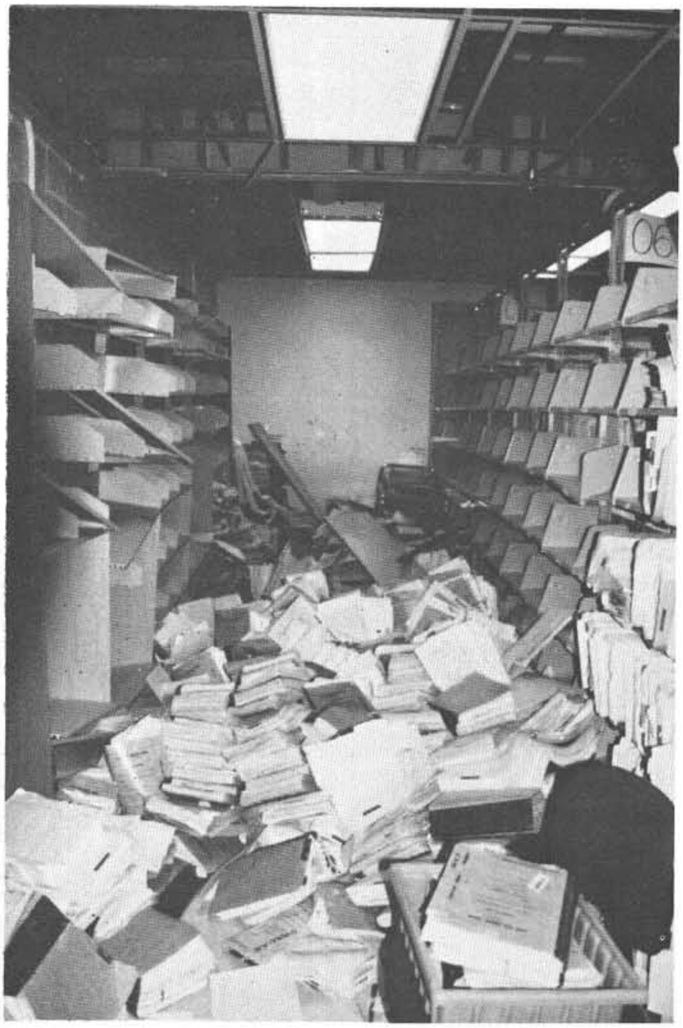

Fig. 35 Overturning of files at basement and nonstructural damage of gypsum boards in roof.

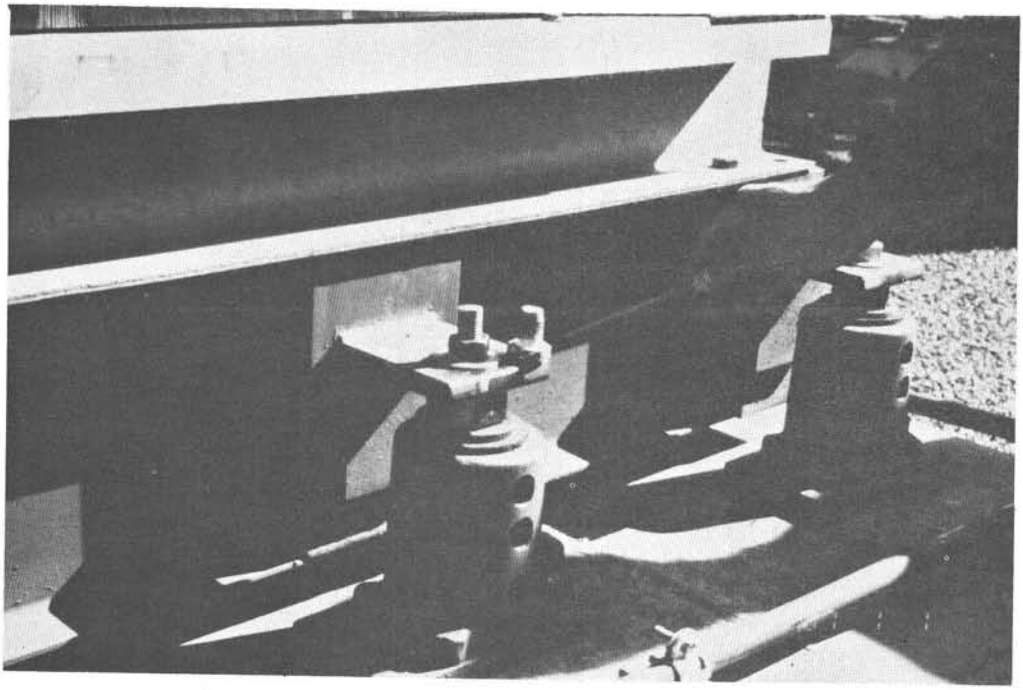

Fig. 36 The base plate of a steel structure allowed relative movements between slab and steel structure.

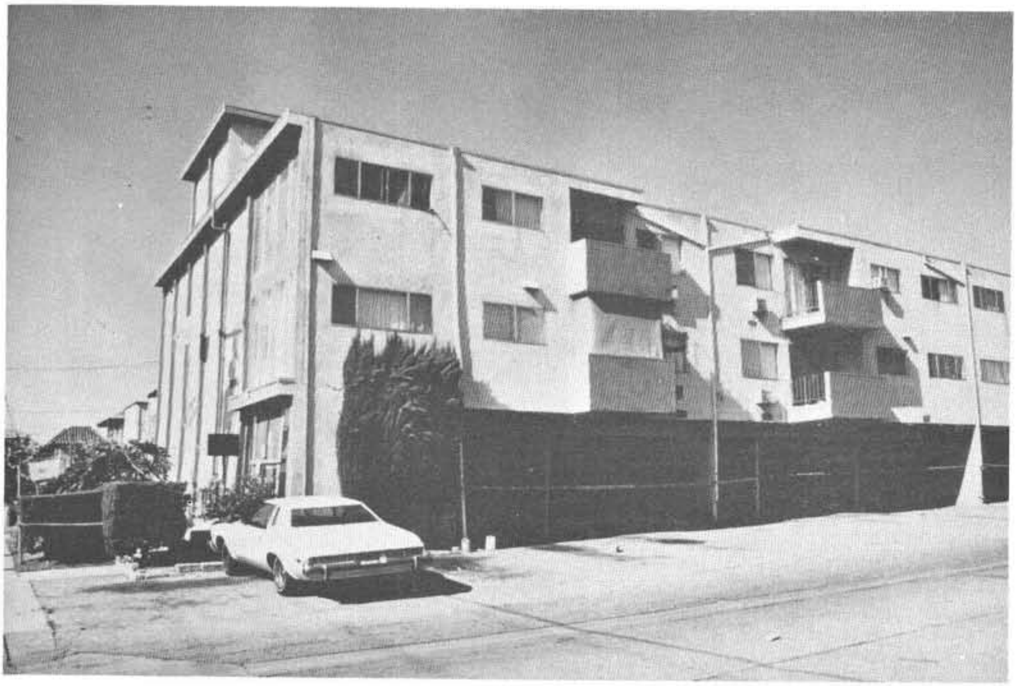

Fig. 37 Typical multi-story dwelling with first floor open spaces for parking.

Fig. 38 Typical wood frames. The structure did not have structural walls.

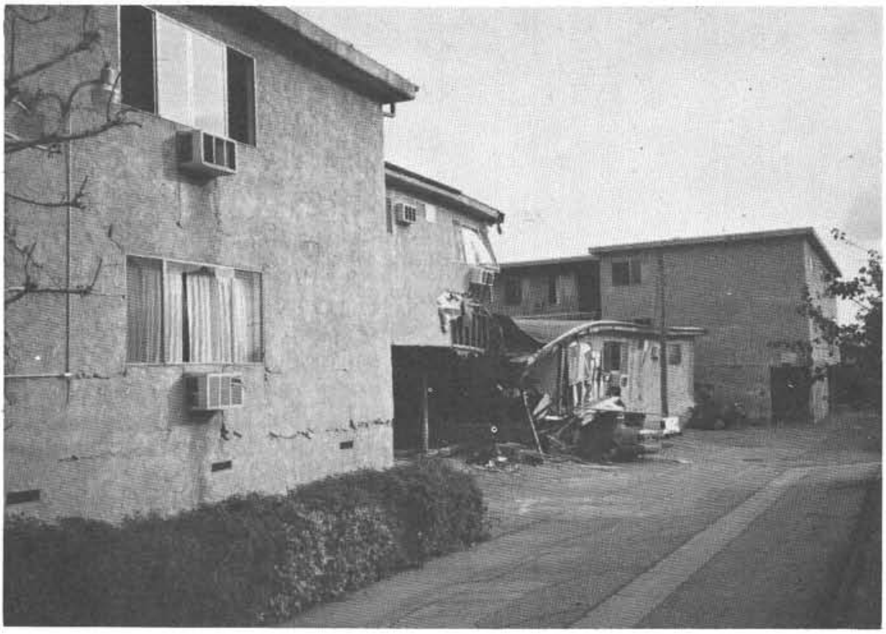

Fig. 39 First soft-story collapse of a timber structure.

Fig. 40 Masonry crushing and out-of-plane failure.

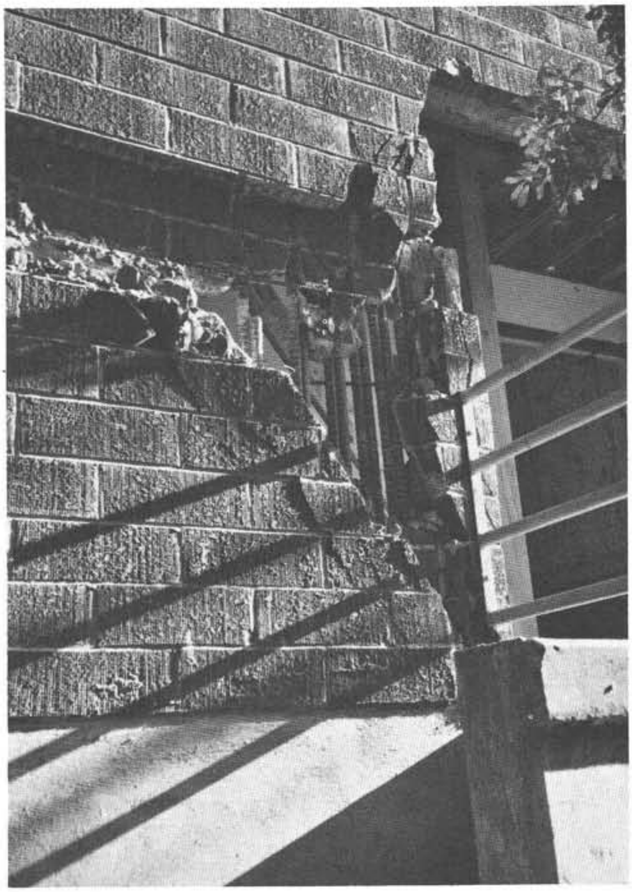

Fig. 41 Diagonal cracking and crushing of heavily reinforced masonry.

Fig. 42 Failure of a masonry chimney.

Fig. 43 Rehabilitation of an URM structure. Anchoring of slabs.

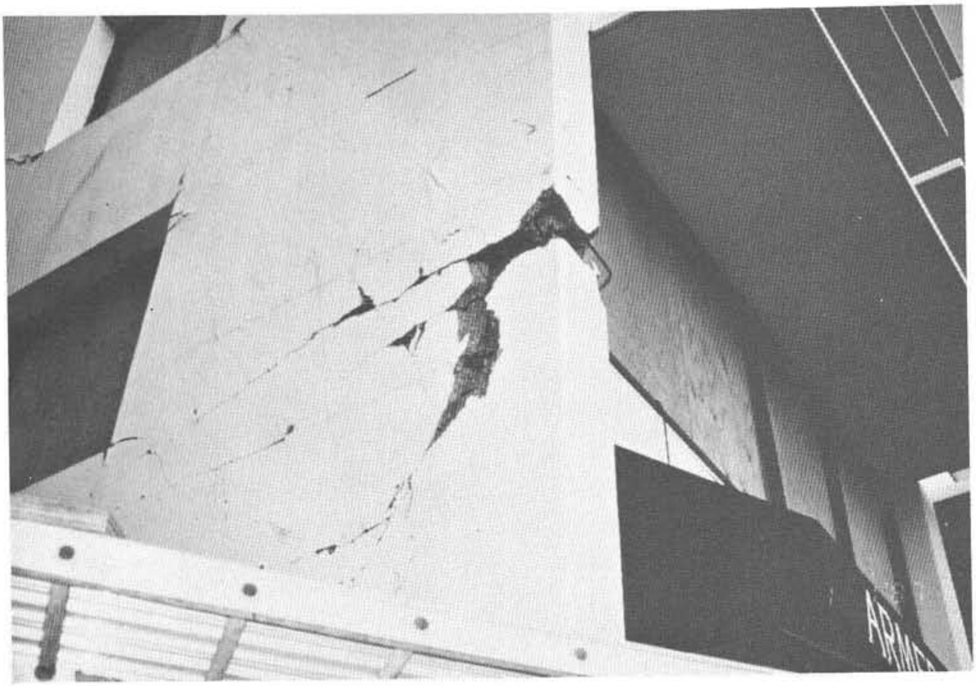

Fig. 44 Splice failure in RC boundary element.

Fig. 45 Damage along construction joints, probably due to bond distress.

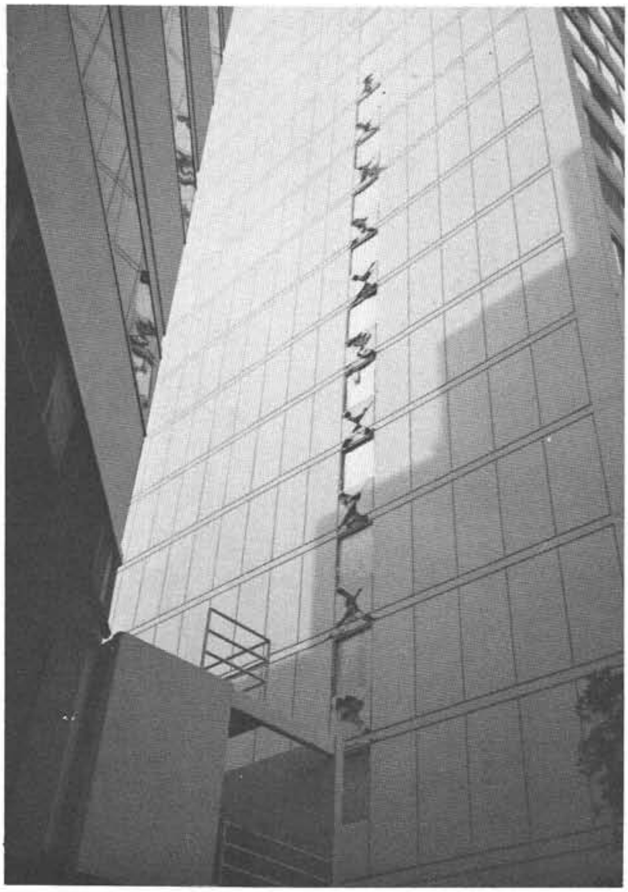

Fig. 46 Diagonal tension failure of coupling beams.

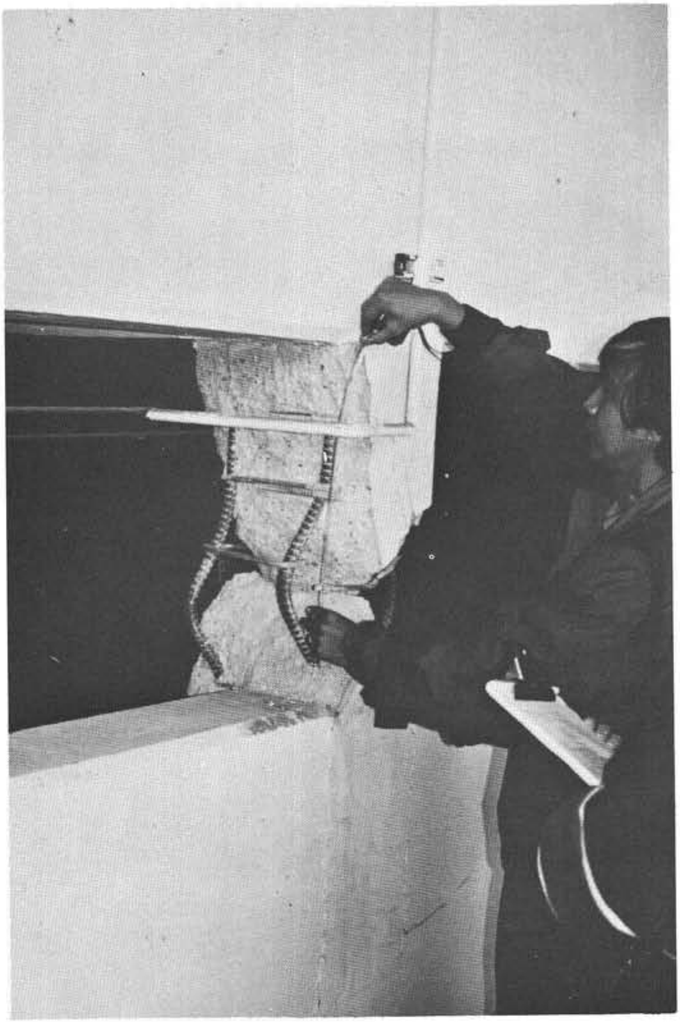

Fig .47 Short column shear failure.

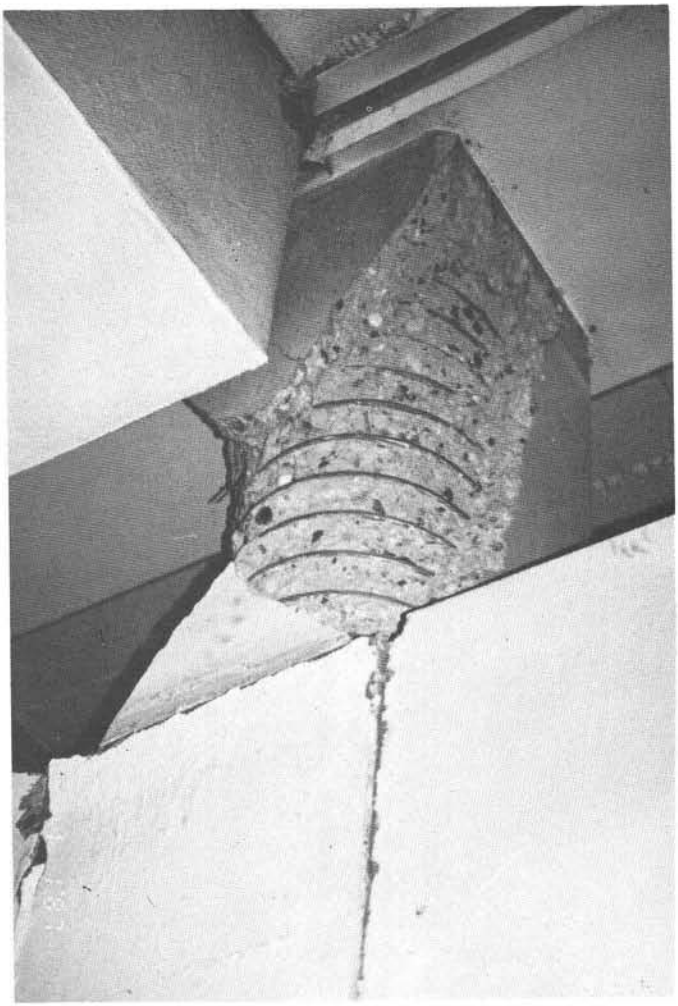

Fig. 48 Short column property confined with spiral reinforcement.

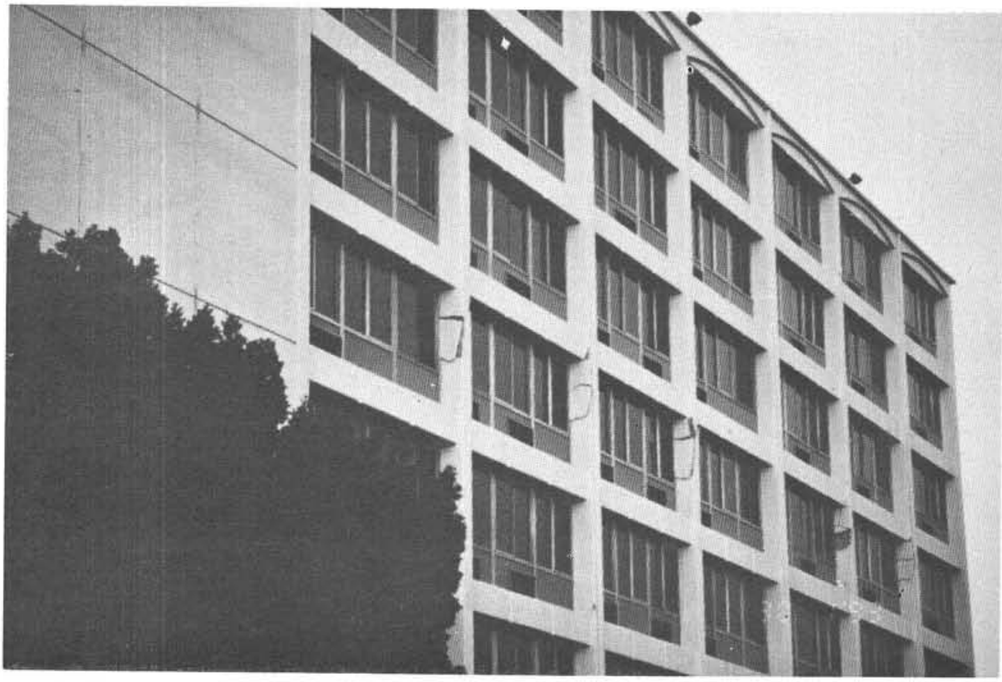

Fig. 49 Diagonal cracking of frame columns.

Fig. 50 CSUN parking structure collapse.

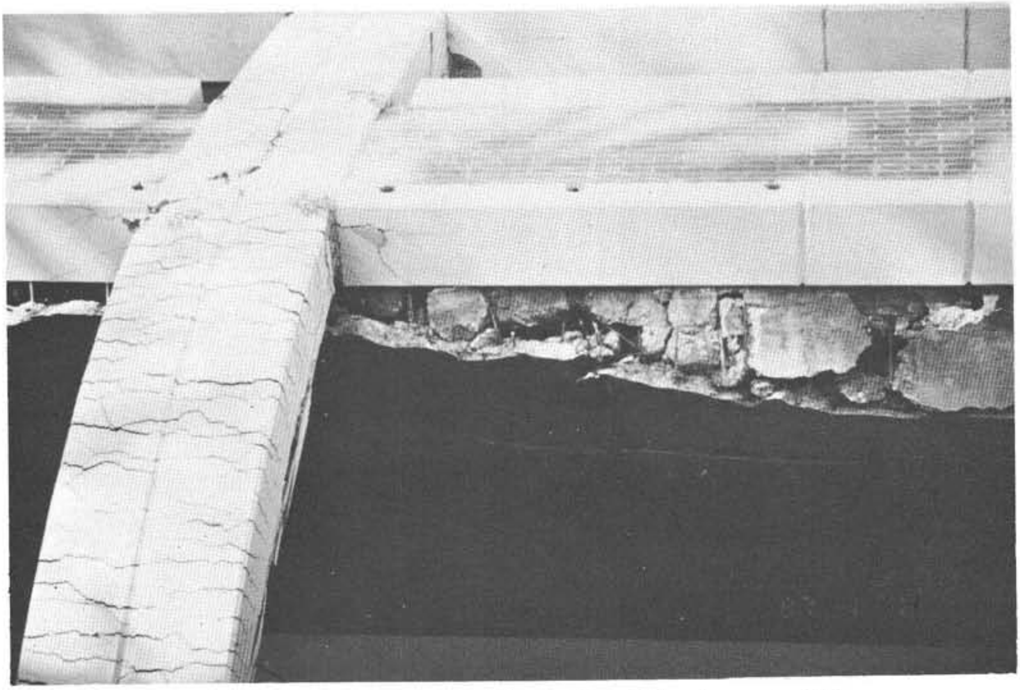

Fig. 51 CSUN parking building. Note RC column ductility

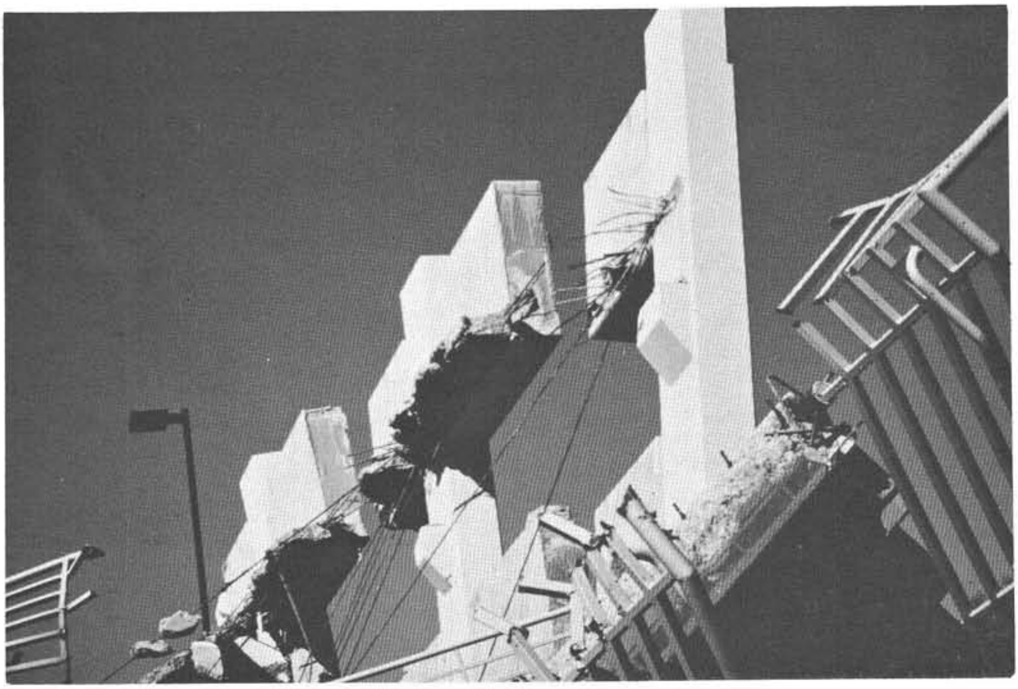

Fig. 52 CSUN parking structure. Note brackets for supporting precast girders and minimal continuity reinforcement.

APPENDIX 1

DATABASE ON THE NORTHRIDGE EARTHQUAKE

ADDRESS	ZONE	DESCRIPTION
6685 Hollywood Blvd and Las Palmas Av.; NE corner	Hollywood	Two-story commercial building with a penthouse. Built around 1930's. URM structure. Shear cracking on walls and piers on second floor. (URM / Low-Rise Commercial)
Hollywood Blvd and Las Palmas Av.; NW corner	Hollywood	Two-story URM commercial building. Diagonal cracking at opening corners.
N side of Hollywood Blvd between Cherokee Av. and Whitley Av.	Hollywood	Pounding of one- and two-story URM commercial buildings.
N side of Hollywood Blvd between Whitley Av. and Hudson Av.	Hollywood	Three-story retrofitted URM commercial building from the 1940's. Crushing of exterior piers perhaps due to upper stories shaking. (Appendix behavior)
6537, 6535 and 6531 1/2 Holloywood Blvd, N side	Hollywood	Eighty year old historical landmark. Retrofitted URM with four floors plus basement. Commercial use at ground floor; others, apartments. Foundation has 1 m thick R/C walls. Diagonal cracking on facade walls. Maximum crack widths were 1cm. No visual structure damage; only plaster cracks. "Limited entry" sign of Jan-22-94.
6381 Hollywood Blvd and Cahuenga St; NE corner	Hollywood	Six-story retrofitted URM commercial building. Historical trust. Cracking on top of wall piers.
Hollywood Blvd and Ivar St; NE corner	Hollywood	Eleven-story retrofitted URM commercial building. Cracking in wall openings.
Vine Street, E side, between Hollywood Blvd and Selma St.	Hollywood	Two-story URM structure built around 1940's-1950's. Fire damage.
Sunset Blvd and Ivar St; NW corner	Hollywood	One-story commercial. Modern steel structures with wood floor trusses. Collapse of false ceiling. No pictures allowed.
Warwick Building 6505 Sunset Blvd and Wilcox; NW corner	Hollywood	Three-story commercial (ground floor) and apartment structure built around 1940's. Retrofitted URM. Corner building with regular plan. Wall shear cracking on E-W facade (Sunset Blvd); almost no cracking on N-S side. Pounding with 6507 Sunset Blvd.
6525 Sunset Blvd; N side	Hollywood	Eight-story URM apartment building. Diagonal cracks on wall piers.
6515 Sunset Blvd; N side	Hollywood	Four-story modern masonry commercial structure. Only two window glasses broken.
6600 and 6606 Sunset Blvd with Seward; SW corner	Hollywood	Two-story URM commercial (ground level) and apartment building. Wall diagonal cracking.

St. Andrew's Liquor Hollywood Blvd.	Hollywood	Two-story building. More than 20 years old. R/C structure in the first story. R/C and masonry structure in the second story. Nonstructural damage in the first floor but severe damage in the corner of the second floor because of no continuity of column and no continuity of tie beams in the joint.
St. Andrew's Liquor Hollywood Blvd.	Hollywood	Corner view and damage in masonry cover of the second story.
St. Andrew's Liquor Hollywood Blvd.	Hollywood	General view of a commercial building.
Hollywood Blvd.	Hollywood	3-story apartment building. Shear cracks in the first story panel walls up to window openings. Maybe 10 years old. Structural panel system.
Hollywood Blvd.	Hollywood	Flexural crack at the bottom of the wall fence and shear cracks in the corner of the window opening of an apartment building.
Hollywood Blvd.	Hollywood	1-story URM structure. Shear cracks and a stiff facade. This structure will be demolished soon. High risk and instability in the floor system.
Hollywood Blvd.	Hollywood	Severe damage in URM one story building with shear cracks.
Hollywood Blvd.	Hollywood	Official document about an structural safety evaluation in this building.
Hollywood Blvd.	Hollywood	Stiff and heavy masonry facade.
Janitorial Hollywood Blvd.	Hollywood	1-story URM commercial building built more than 30 years ago. Double wythe wall. Shear cracks and spall of corner masonry in the facade.
Janitorial Hollywood Blvd.	Hollywood	Corner view of double wythe URM wall with shear cracks.
Vacancy Hotel Hollywood Blvd.	Hollywood	4-story URM building with timber floor and roof system anchored to exterior walls with post-tensioned steel round bars. Shear cracks in walls up to opening edges. Shear damage in transverse wall. This structure damaged another small neighbor (pounding).
Vacancy Hotel Hollywood Blvd.	Hollywood	Damage due to pounding between neighbor buildings without enough separation.
Vacancy Hotel Hollywood Blvd.	Hollywood	Shear cracks in URM walls in the facade of the Hotel.

Vacancy Hotel Hollywood Blvd.	Hollywood	Transverse URM walls and details of anchorages to fix the timber floor system to masonry walls. Shear cracks in wall along mortar joints.
Hollywood Blvd.	Hollywood	4-story apartment URM building. Partial collapse of the north corner. Spectacular collapse. No separation from neighbor construction. Double wythe masonry walls and heavy loads in each story.
Hollywood Blvd.	Hollywood	Partial collapse of the corner in a URM 4-story building.
Hollywood Blvd.	Hollywood	Severe partial collapse of roof system and out-of-plane failure in URM one-story commercial building.
Bledsoe St between Bradley Av and Woodcock Av.	Sylmar	Six-story R/C office structure. Cracking at construction joints. Crushing on ground floor columns.
Olive View Medical Center - Main building	Sylmar	Five-story county hospital which replaces the 1971collapsed building. Located on alluvium. Underground with R/C walls; elevator (7 units) and machinery pent-house. Built in 1975 although occupied until 1985 due to safety and health requirements. Surgical hospital with 350 beds (the original had 850 beds). Structure is made of welded steel shapes. Slab system consists of metal decking with concrete topping. Columns are spaced at 20 ft. R/C walls in the basement (box-type foundation) and in elevator core. Story height is 18 ft. No structural damage reported in the steel structure. Diagonal cracking in basement walls at 20 cm spacing and 0.010 inch wide. Flexural cracking in edges. Column size in the basement is 50 cm. Water damage in fifth floor and fourth floor due to fracture of a 1 inch diameter cooper pipes (bad solder fracture). Seven sprinkler black iron pipes broke in same floors. Machinery sliding due to ripping of anchor bolts due to reduced length over the nut. USGS has two instruments: 2.3g in the sixth floor and 0.9g at the base. The sixth story apparatus is located at most in the center of the cross-shaped building (which goes from 4th to 6th floors).
Olive View Medical Center Olive View Dr.	Sylmar	Nonstructural elements in floor systems and nonstructural damage in small diameter pipes for water supply located at the bottom face of the floor system.
Olive View Medical Center Olive View Dr.	Sylmar	Damage in nonstructural gypsum board in roof due to lateral movements of the structure
Olive View Medical Center Olive View Dr.	Sylmar	No damage in office room located in the 6th. story of the building
Olive View Medical Center Olive View Dr.	Sylmar	Beam-column joint and pipes in machinery room at the top of the building.
Olive View Medical Center Olive View Dr.	Sylmar	Screws in the base of the electric transformer in the roof level.

Olive View Medical Center Olive View Dr.	Sylmar	General view of roof level and machinery room.
Olive View Medical Center Olive View Dr.	Sylmar	Base plate which supports a steel structure where relative movement between slab and steel structure occurred.
Olive View Medical Center Olive View Dr.	Sylmar	Exterior view of windows facade.
Olive View Medical Center Olive View Dr.	Sylmar	General view of the parking lot.
Olive View Medical Center Olive View Dr.	Sylmar	Lamp in machinery room at roof level.
Olive View Medical Center Olive View Dr.	Sylmar	Interior view of machinery room (transformer), tie bar (tensor) which fixes the equipment to the slab to preclude displacements.
Olive View Medical Center Olive View Dr.	Sylmar	Base plate and screws of a steel structure, no damage.
Olive View Medical Center Olive View Dr.	Sylmar	Checking the lower part of the roof system without nonstructural elements.
Olive View Medical Center Olive View Dr.	Sylmar	Overturning of files at the basement.
Olive View Medical Center Olive View Dr.	Sylmar	Main entrance of the Hospital. No damage.
Olive View Medical Center Olive View Dr.	Sylmar	General view of the O!ive View Medical Center.
Olive View Medical Center Olive View Dr.	Sylmar	General view of the Olive View Medical Center.
Olive View Medical Center - Warehouse Olive View Dr.	Sylmar	Tilt-up structure with R/C concrete walls and a steel and wood roof. Diagonal cracking in some panels near the base. Joint opening between panels. Damage near the connection with roof. Panel horizontal deflection at mid-height at rear of building. Several interior lamps were sheared off and fell. Separation of roof panels.
Olive View Medical Center Olive View Dr.	Sylmar	Precast building for warehouse with R/C walls. Detail of the separation between precast walls.

Olive View Medical Center Olive View Dr.	Sylmar	Roof system of the warehouse. No damage.
Olive View Medical Center Olive View Dr.	Sylmar	Base plate and screws of the steel shelf in the warehouse. Possible relative movement in the base plate respect to the floor slab.
Olive View Medical Center Olive View Dr.	Sylmar	Column support of transverse beam in roof. Warehouse of the Olive View Medical Center.
Sylmar Electric Power Substation	Sylmar	Damaged ceramic elements.
Varsity Club Apartments 10020 Zelzah Ave.	Northridge	Four-story apartment building (upper three floors). Corner building. Basement N and E walls are fully grouted CMU. W and S columns made of stack bonded CMU. Shear cracks on walls and columns. No damage noted in interior 30 cm round R/C columns in the basement. No distress in the 25x70 cm slab drop panel. Upper floors have wood framing covered with stucco reinforced with a mesh. Damage along panel joints.
Varsity Club Apartments 10020 Zelzah Ave	Northridge	Front view of apartments and street.
Varsity Club Apartments 10021 Zelzah Ave	Northridge	Shear cracks in column and beam from upper right corner of window opening.
Varsity Club Apartments 10022 Zelzah Ave	Northridge	Front view of the apartment complex.
Varsity Club Apartments 10023 Zelzah Ave	Northridge	Shear crack in column of the first level which is used as parking lot. Possible first soft floor.
Varsity Club Apartments 10024 Zelzah Ave	Northridge	Exterior view without damage to balconies.
Varsity Club Apartments 10025 Zelzah Ave	Northridge	Severe column damage. Columns built with stucco reinforced with a mesh along joints.
RM Garden Walls or Fences Zelzah Ave	Northridge	Damage in RM garden wall; partially collapsed.
RM Garden Walls or Fences Zelzah Ave	Northridge	Detail of spliced rebars inside the hollow blocks. Partial collapse.

RM Garden Walls or Fences Zelzah Ave	Northridge	General view of continuous RM garden wall along the street.
RM Garden walls Around CSU campus near Zelzah and Nordhoff Streets	Northridge	Out-of-plane damage (collapse) in garden walls.
RM Garden walls Around CSU campus near Zelzah and Nordhoff Streets	Northridge	Concrete hollow bricks of a collapsed garden wall. Partial grouting of cells.
Nordhoff St.	Northridge	Indirect grouted masonry garden fence.
Mountain View Apartments 9950 Zelzah Ave.	Northridge	Three-story building. Wood frame structure with steel poles in the garage. Twisted and leaning to W side. Declared unsafe.
CSU Northridge Campus Zelzah Ave near Nordhoff St; W side	Northridge	Buildings inside of the CSU campus.
Parking Building - CSU Northridge Campus Zelzah Ave. near Nordhoff St; W side	Northridge	Four-story precast concrete structure. Unbonded post-tensionedtwo-way slabs. Precast columns with vertical post-tensioning. Precast beams on column corbels. In both directions, columns every two other beams. N-S span was about 5 m. Collapse of E and W sides of the building. Diagonal cracking of beam-column joints in the N-S direction. Column ductile failure (bending) except in a couple of columns. Possibly interior columns failed thus causing inward collapse. Catenary action of slabs was noticed. Few unbonded tendon anchorage failure due to collapse.
Parking building inside CSU Northridge Campus Zelzah Ave near Nordhoff St; W side	Northridge	Front view of the most damage area.
Parking building inside CSU Northridge Campus Zelzah Ave near Nordhoff St; W side	Northridge	Collapse of the last bay and severe flexural damage in a column of the first story.
Parking building inside CSU Northridge Campus Zelzah Ave near Nordhoff St; W side	Northridge	General view of the collapsed structure.
Parking building inside CSU Northridge Campus Zelzah Ave near Nordhoff St; W side	Northridge	Partial collapse of the parking building and standing of three columns.
Parking building inside CSU Northridge Campus Zelzah Ave near Nordhoff St; W side	Northridge	Flexural cracks in column and partial collapse of the parking building.
Parking building inside CSU Northridge Campus Zelzah Ave near Nordhoff St; W side	Northridge	Partial collapse of the last two bays.

Parking building inside CSU Northridge Campus Zelzah Ave near Nordhoff St; W side	Northridge	Collapse of the last two bays and details of flexural cracks in R/C column.
Parking building inside CSU Northridge Campus Zelzah Ave near Nordhoff St; W side	Northridge	Collapse and details of post-tensioned slab cables.
Parking building inside CSU Northridge Campus Zelzah Ave near Nordhoff St; W side	Northridge	Column and slab failure. Lack of continuity among precast elements. Flexural cracks along the height of the column.
Parking building inside CSU Northridge Campus Zelzah Ave near Nordhoff St; W side	Northridge	Stairs failure as an independent body due to the collapse of the parking.
Parking building inside CSU Northridge Campus Zelzah Ave near Nordhoff St; W side	Northridge	Plastic hinge in a beam end near the beam-column joint
Parking building inside CSU Northridge Campus Zelzah Ave near Nordhoff St; W side	Northridge	Collapsed area and standing of three columns showing the precast connections.
Parking building inside CSU Northridge Campus Zelzah Ave near Nordhoff St; W side	Northridge	Exterior frame showing the damage to unbonded post-tensioned slabs.
Parking building inside CSU Northridge Campus Zelzah Ave near Nordhoff St; W side	Northridge	Detail of secondary beams joint and slab collapse.
Parking building inside CSU Northridge Campus Zelzah Ave near Nordhoff St; W side	Northridge	Collapse of stair area. The platform was overturned to a vertical position.
Parking building inside CSU Northridge Campus Zelzah Ave near Nordhoff St; W side	Northridge	Slab damage.
Parking building inside CSU Northridge Campus Zelzah Ave near Nordhoff St; W side	Northridge	Detail of joint between main and secondary beam under the collapsed slab.
Parking building inside CSU Northridge Campus Zelzah Ave near Nordhoff St; W side	Northridge	Flexural and shear cracks in a column
Parking building inside CSU Northridge Campus Zelzah Ave near Nordhoff St; W side	Northridge	Collapse of floor slabs and flexural cracks at the ends of a first story column.
Parking building inside CSU Northridge Campus Zelzah Ave near Nordhoff St; W side	Northridge	General view of the parking collapse. Column ductile failure

CSU Northridge Campus Zelzah Ave near Nordhoff St; W side	Northridge	New apartment, 4-story buildings inside CSU campus
CSU Northridge Campus Zelzah Ave near Nordhoff St; W side	Northridge	Two-story apartment buildings inside CSU campus
CSU Northridge Campus Zelzah Ave near Nordhoff St; W side	Northridge	Two-story apartments inside CSU campus. Severe damage at the base of these wooden structures
The Superior Apartment Building Zelzah Ave; E side	Northridge	Three-story 18-apartment units. Upper wood frame with stucco over E-W soft-garage level with steel poles. First soft story collapse.
University Residency Town - CSU Campus Lassen St and Zelzah Ave; NW corner	Northridge	Seven-story R/C building. Damage at construction joints between building and stair core though they are continuous at the top (parapet). Wall diagonal cracking in the second floor; crushing. No damage in the ground floor; no distress in the R/C structure.
University Residency Town - CSU Campus Lassen St. and Zelzah Ave. NW corner	Northridge	Seven-story R/C building.
University Residency Town - CSU Campus Lassen St. and Zelzah Ave. NW corner	Northridge	Seven-story building.
University Residency Town - CSU Campus Lassen St. and Zelzah Ave. NW corner	Northridge	Damage in the second story corner only in the brick finish cover.
University Residency Town - CSU Campus Lassen St. and Zelzah Ave. NW corner	Northridge	Diagonal shear cracks in a wall of the second story showing the rebars.
University Residency Town - CSU Campus Lassen St. and Zelzah Ave. NW corner	Northridge	Damage at the top parapet in the joint between the building and the stair core.
University Residency Town - CSU Campus Lassen St. and Zelzah Ave. NW corner	Northridge	Shear cracks in the second story exterior walls.
University Residency Town - CSU Campus Lassen St. and Zelzah Ave. NW corner	Northridge	New 4-story office building without any damage in the Northridge zone.
University Residency Town CSU Campus Lassen St. and Zelzah Ave. NW corner	Northridge	Damage in one-story wooden houses. URM chimney fell down.

Apartment building Dearborn and Yolanda St.	Northridge	Three stories; 24 apartments. Open ground floor: in the E-W direction there are sheat-rock walls covered with stucco. For the N-S direction, steel pole columns (6-in. diameter) covered with mesh and stucco. Steel pole typical spacing was 5 m; however, column size and spacing vary widely. Red-tagged. Significant story drift in first story.
Apartment Building Dearborn and Yolanda Streets	Northridge	General view in Yolanda Ave. Three-story buildings with open ground floor.
Apartment Building Dearborn and Yolanda Streets	Northridge	Severe damage in the first floor walls mainly on its stucco cover.
Apartment Building Dearborn and Yolanda Streets	Northridge	Steel pole column (6 in-diameter) covered with mesh and stucco.
Apartment Building Dearborn and Yolanda Streets	Northridge	Damage at the top of the column only in cover of beam ends.
Apartment Building Dearborn and Yolanda Streets	Northridge	Crushing of stucco cover and vertical crack at the base of the column.
Apartment Building Dearborn and Yolanda Streets	Northridge	Vertical crack in a wall and flexural cracks at the base near the foundation beam. Possible slip failure in the wall.
Apartment Building Dearborn and Yolanda Streets	Northridge	Severe damage at the top and bottom of the 6-in diameter column. Permanent deformation out of the original vertical line is noted.
Apartment building 19039 Nordhoff St, between Vanalden Ave and Wilbur Ave; N side	Northridge	Three stories. Groundf floor (parking) made of fully grouted CMU: along E side all wall; on W side CMU columns. Interior 12-in diameter R/C columns with a 70 x 70 x 25 cm slab drop panel. Diagonal cracks in N-S and E-W walls. Crushing in top of columns for E-W movement (parallel to Nordhoff St).
Apartment Building 19039 Nordhoff St., between Vanalden Ave. and Wilbur Ave.; North side	Northridge	Damage at the bottom of a circular R/C column in the ground floor.
Apartment Building 19040 Nordhoff St., between Vanalden Ave. and Wilbur Ave.; North side	Northridge	The concrete cover at the top of the column was crushed.
Apartment Building 19041 Nordhoff St., between Vanalden Ave. and Wilbur Ave.; North side	Northridge	Shear crack and damage at the top of the column in the boundary with the column head.

Apartment Building 19042 Nordhoff St., between Vanalden Ave. and Wilbur Ave.; North side	Northridge	Spalling of concrete cover at the bottom of the concrete (crushing).
Apartment Building 19043 Nordhoff St., between Vanalden Ave. and Wilbur Ave.; North side	Northridge	Shear and vertical cracks along the height of the column.
Apartment Building 19044 Nordhoff St., between Vanalden Ave. and Wilbur Ave.; North side	Northridge	Shear crack in a R/C masonry wall.
Apartment Building 19045 Nordhoff St., between Vanalden Ave. and Wilbur Ave.; North side	Northridge	Spalling of concrete at the floor level.
Apartment Building 19046 Nordhoff St., between Vanalden Ave. and Wilbur Ave.; North side	Northridge	Notice of limited entry to a high risk damaged structure.
Apartment building 19053 Nordhoff St, between Vanalden Ave and Wilbur Ave; N side	Northridge	Similar damage to 19039 Nordhoff St.
Apartment building 19201 Nordhoff St, between Vanalden Ave and Tampa Ave; N side	Northridge	Three stories wood structure. Damage in wood framing covered with stucco (concrete block wall).
Apartment Building 19201 Nordhoff St., between Vanalden Ave. and Tampa Ave.; North side	Northridge	Collapse of URM facade of a wood structure. Damage in wood framing oovered with stucco.
GW Parking Building 19808 Praire St. between Oakdales Ave. and Penfield Ave.; N side	Northridge	General view of precast beams in EW direction (span was almost 20m).
19500 Nordhoff St. (and Shirley Ave)	Northridge	Damage on 37.
GW parking building 19808 Prairie St between Oakdale Av and Penfield Av; S side	Northridge	Three stories. R/C frames in the N-S direction. EW precast beams. Square columns 60 cm sides. Four walls on each side 30 cm thick and 5 m long. EW beam span was 19.3 m (58 ft). Slab thickness was 17.5 cm (unbonded post-tensioned slabs). Minor column shear cracking next to ramps. Wall diagonal cracking.
GW Parking Building 19809 Praire St. between Oakdales Ave. and Penfield Ave.; N side	Northridge	Interior view of the parking structure and precast beam in EW direction.
GW Parking Building 19811 Praire St. between Oakdales Ave. and Penfield Ave.; N side	Northridge	Exterior view of R/C frames in N-S direction. 3-story building.

GW Parking Building 19812 Praire St. between Oakdales Ave. and Penfield Ave.; N side	Northridge	Intersection of beams in N-S and E-W directions.
GW Parking Building 19813 Praire St. between Oakdales Ave. and Penfield Ave.; N side	Northridge	Beam-column joint with small size flexural cracks at the bottom of the beam.
GW Parking Building 19814 Praire St. between Oakdales Ave. and Penfield Ave.; N side	Northridge	Hair-line flexural cracks at the base of square columns 60 cm sides.
GW Parking Building 19815 Praire St. between Oakdales Ave. and Penfield Ave.; N side	Northridge	Detail of ramp connection with a column and perpendicular like R/C wall and beam.
GW Parking Building 19816 Praire St. between Oakdales Ave. and Penfield Ave.; N side	Northridge	Small width shear diagonal cracks in column due to possible short-column effect because of ramp and beam connections to the column.
GW Parking Building 19817 Praire St. between Oakdales Ave. and Penfield Ave.; N side	Northridge	Exterior back view of the GW parking building.
Northridge Fontana Apartment Building 18547 Plummer St. with Reseda Blvd.	Northridge	First soft floor collapse in a three stories wood structure.
Northridge Meadows Apartment Building 9565 Reseda Blvd between Plummer St. and Citronia St.	Northridge	Two stories and 22 apartments wood structure. Garage in ground floor with steel poles (EW direction). Collapsed first story; almost no damage in second floor. Sixteen people killed.
Northridge Fontana Apartment Building 18547 Plummer St. with Reseda Blvd.	Northridge	Three stories wood structure. First soft floor collapse.
Northridge Meadows Apartment Building 9565 Reseda Blvd. between Plummer St and Citronia	Northridge	External view of the two stories series apartments with garage in ground floor.
Northridge Meadows Apartment Building 9566 Reseda Blvd. between plummer St and Citronia	Northridge	Collapse of the last apartment with first soft floor.
Northridge Meadows Apartment Building 9567 Reseda Blvd. between Plummer St and Citronia	Northridge	General view of damage between two adjacent neighbor structures due to pounding.
WoodridgeApartment Building 18540 Plummer St with Reseda Blvd.	Northridge	Two stories wood structure. Collapse of open garage story (NS direction). Three cars crushed.

Woodridge Apartment building 18540 Plummer St with Reseda Blvd.	Northridge	Collapse of open garage story (NS direction). One crushed car.
Robinson's - May Parking Structure in Northridge Shopping Center Nordhoff St.	Northridge	R/C shear walled parking building. Demolished.
118 Simi Valley - San Fernando Valley Freeway San Fernando Mission Blvd and Debra Av.	Granada Hills	Shear compression failure in bridge columns. Longitudinal steel (#11 bars) buckled and fractured #5 spiral reinforcement. Failure at section damage along the column. Flexural cracking in box girder due to column failure. Crushing in the W support at the abutment. Next to Valjean Av., columns are crushed at different heights. The columns had a uniform section.
118 Simi Valley - San Fernando Valley Freeway San Fernando Mission Blvd. and Debra Av.	Granada Hills	Shoring under Freeway #118.
118 Simi Valley - San Fernando Valley Freeway San Fernando Mission Blvd. and Debra Av.	Granada Hills	Steel support structure located al the end of the bridge.
118 Simi Valley - San Fernando Valley Freeway San Fernando Mission Blvd. and Debra Av.	Granada Hills	Spalling of concrete cover in the parapet joint between two precast bridges.
118 Simi Valley - San Fernando Valley Freeway San Fernando Mission Blvd. and Debra Av.	Granada Hills	Lateral view of shoring and parapet of the freeway.
118 Simi Valley - San Fernando Valley Freeway San Fernando Mission Blvd. and Debra Av.	Granada Hills	Detail of the bottom part of the shore.
118 Simi Valley - San Fernando Valley Freeway San Fernando Mission Blvd. and Debra Av.	Granada Hills	Spalling of concrete cover at the top of a bridge column compression failure.
118 Simi Valley - San Fernando Valley Freeway San Fernando Mission Blvd. and Debra Av.	Granada Hills	Shear compression failure and rebar buckling in a bridge R/C column.
118 Simi Valley - San Fernando Valley Freeway San Fernando Mission Blvd. and Debra Av.	Granada Hills	General view of shoring work around the bridge column with a large compression failure.
118 Simi Valley - San Fernando Valley Freeway San Fernando Mission Blvd. and Debra Av.	Granada Hills	Longitudinal view through the freeway showing the shoring work.

118 Simi Valley - San Fernando Valley Freeway San Fernando Mission Blvd. and Debra Av.	Granada Hills	Compression failure at the bottom of the bridge column. Crushing of concrete and rebar buckling in Freeway 118
118 Simi Valley - San Fernando Valley Freeway San Fernando Mission Blvd. and Debra Av.	Granada Hills	Longitudinal view of Freeway 118.
118 Simi Valley - San Fernando Valley Freeway San Fernando Mission Blvd. and Debra Av.	Granada Hills	Shear compression failure in a series of trasverse bridge columns. Column concrete is crushed at different heights.
118 Simi Valley - San Fernando Valley Freeway San Fernando Mission Blvd. and Debra Av.	Granada Hills	General view of the end part of the bridge in Freeway 118.
Roscoe Blvd	Sepulveda	Collapsed grouted masonry fences.
Holiday Inn Express Hotel Roscoe Blvd between Orion Ave and Langdon Ave.	Sepulveda	Seven-story R/C frame. Mostly damaged in the EW direction. Shear cracking in fourth floor. N and S face columns ("captive" column). Diagonal cracking in beam-column joints from second to fourth stories. Parapet crushing at first floor. CSMIP records.
Holiday Inn Express Hotel Roscoe Blvd. Orion Ave and Langdon Ave	Sepulveda	Diagonal cracking in beam-column joints from second to fourth stories.
Holiday Inn Express Hotel Roscoe Blvd. Orion Ave and Langdon Ave	Sepulveda	Detail of flexural cracking at the end of beam in the second story.
Holiday Inn Express Hotel Roscoe Blvd. Orion Ave and Langdon Ave	Sepulveda	Small damage at the end of the column above the parapet due to short-column effect.
Holiday Inn Express Hotel Roscoe Blvd. Orion Ave and Langdon Ave	Sepulveda	Damage in a series of columns in the fourth story back view.
Holiday Inn Express Hotel Roscoe Blvd. Orion Ave and Langdon Ave	Sepulveda	Shear cracks in the external face of a beam-column joint (second story).
Holiday Inn Express Hotel Roscoe Blvd. Orion Ave and Langdon Ave	Sepulveda	Front view of the building showing the frame structure
Robinson - May Parking Building - Westside Pavilion Across from 2472 Overland between Pico Bl. and Pico Av.	Rancho Park	Three stories including a basement. Cast-in-place R/C frame structure. Short column type failure. Column section 35 x 40 cm. Column ties #3 @ 15 cm with 90-deg hooks. The effective length of column was 65 cm. Columns damaged in the basement. It is being demolished.

Robinson -May parking building- West Side Pavilion Across 2472 Overland between Pico Blvd. and Pico Av.	Rancho Park	General view of the West-Side Pavilion Commercial Center.
Robinson -May parking building- West Side Pavilion Across 2472 Overland between Pico Blvd. and Pico Av.	Rancho Park	Short-column type failure with spalling of concrete.
Robinson -May parking building- West Side Pavilion Across 2472 Overland between Pico Blvd. and Pico Av.	Rancho Park	Shear cracks along the height of the column next to the ramp.
Robinson -May parking building- West Side Pavilion Across 2472 Overland between Pico Blvd. and Pico Av.	Rancho Park	Spalling of concrete cover in a construction joint of a R/C parapet beside the ramp.
Robinson -May parking building- West Side Pavilion Across 2472 Overland between Pico Blvd. and Pico Av.	Rancho Park	Typical short-column failure in a column with an effective length of 65 cm buckling of transverse steel.
Santa Monica Freeway Santa Monica Freeway and La Cienega Bl.	Rancho Park	Column failure showing #12 longitudinal bars buckled and #4 spiral reinforcement at 30 cm spacing fractured. Column diameter was 1.2 m. Box girder of the superstructure had a 40 cm thick web (approximately) and 20 cm thick flanges. Across the street several apartment units did not exhibit damage.
Santa Monica Freeway Santa Monica Freeway and La Cienega Blvd	Rancho Park	General view of Santa Monica Freeway demolition.
Santa Monica Freeway Santa Monica Freeway and La Cienega Blvd	Rancho Park	Column failure with rebar buckling and crushing of concrete. Longitudinal beams were box-type.
Santa Monica Freeway Santa Monica Freeway and La Cienega Blvd	Rancho Park	Cleaning work in the stores which were located under the freeway.
Santa Monica Freeway Santa Monica Freeway and La Cienega Blvd	Rancho Park	Detail of failure at the top of the column and joint with the box-type girder actually under demolition.
Santa Monica Freeway Santa Monica Freeway and La Cienega Blvd	Rancho Park	Demolition work with a drag shovel machine.
Santa Monica Freeway Santa Monica Freeway and La Cienega Blvd	Rancho Park	Several apartment units across the street without any damage.

Santa Monica Freeway Santa Monica Freeway and La Cienega Blvd	Rancho Park	Santa Monica freeway under demolition work.
Santa Monica Freeway Santa Monica Freeway and La Cienega Blvd	Rancho Park	Front view of box-type girders and failure at upper part of a column with rebar buckling.
Santa Monica Freeway Santa Monica Freeway and La Cienega Blvd	Rancho Park	Detail of failure at the top of a column with buckling of longitudinal bars and concrete crushing.
Santa Monica Freeway Santa Monica Freeway and La Cienega Blvd	Rancho Park	Front view of box type girders showing a difference of elevation due to more damage in the right side columns.
Santa Monica Freeway Santa Monica Freeway and La Cienega Blvd	Rancho Park	Column failure with an impressive buckling of steel bars and concrete crushing along the height. The freeway was supported after the column failure by the commercial rooms located under the bridge.
Kaiser Permanente Regional Hospital Venice Blvd near La Cienega Blvd.	Rancho Park	The hospital includes a main building (built in 1972) and two adjacent towers built in 1982 and 1987. One steel frame parking building collapsed. A R/C parking structure showed cracks along the construction joints. No damage was visible in the EW precast beams wich were simply supported on columns. Shear cracking was observed in columns next to the corbel. Slight parapet crushing was also noted. No damage was observed in the CMU stairs at corners.
Kaiser Permanente Medical Center Venice Blvd. near La Cienega Blvd.	Rancho Park	General view of main entrance on Venice Blvd.
Kaiser Permanente Medical Center Venice Blvd. near La Cienega Blvd.	Rancho Park	Hospital name Legend.
Kaiser Permanente Medical Center Venice Blvd. near La Cienega Blvd.	Rancho Park	Interior room view (dark slide).
Kaiser Permanente Medical Center Venice Blvd. near La Cienega Blvd.	Rancho Park	Back view of Kaiser Hospital.
Kaiser Permanente Medical Center Venice Blvd. near La Cienega Blvd.	Rancho Park	Facade on the ambulance entrance.
Kaiser Permanente Medical Center Venice Blvd. near La Cienega Blvd.	Rancho Park	R/C parking structure; beam column joint detail.

Kaiser Permanente Medical Center Venice Blvd. near La Cienega Blvd.	Rancho Park	Corner view of the parking R/C structure.
Kaiser Permanente Medical Center Venice Blvd. near La Cienega Blvd.	Rancho Park	Damage below the column supports for the precast beams in transversal direction.
Kaiser Permanente Medical Center Venice Blvd. near La Cienega Blvd.	Rancho Park	R/C beams-parapets in the longitudinal direction of the parking structure.
Kaiser Permanente Medical Center Venice Blvd. near La Cienega Blvd.	Rancho Park	Parking structure back view (not so clear).
Kaiser Permanente Regional Hospital Venice Blvd. near La Cienega Blvd.	Rancho Park	Damage at the end of the R/C parapet beam next to the column. Longitudinal direction of the parking building.
Kaiser Permanente Regional Hospital Venice Blvd. near La Cienega Blvd.	Rancho Park	Back view of the parking building. Damage at the top a column with crushing of cover concrete.
Kaiser Permanente Regional Hospital Venice Blvd. near La Cienega Blvd.	Rancho Park	Typical damage of a strong parapet beam and weak column. Back side of the parking building.
Kaiser Permanente Regional Hospital Venice Blvd. near La Cienega Blvd.	Rancho Park	Shear crack in a R/C wall opened in a small angle in two directions.
Landslide failure on Beach road Beach road near Sta. Monica freeway	Santa Monica	General view of landslide.
Sta. Monica Blvd.	Santa Monica	Two-story house roof collapse.
Public office 1231 Lincoln Street	Santa Monica	One-story URM structure with partial collapse of its facade (mainly the parapet). The roof system is composed by wood members. There are many window openings in the main facade. Shear cracks were identified on transversal boundary wall. Possible pounding between this structure and neighbor building because there was not enough separation.
Public office 1232 Lincoln Street	Santa Monica	Front view of the public office in Lincoln #1231. Partial collapse of the facade.
Public office 1233 Lincoln Street	Santa Monica	Lincoln Avenue. R/C buildings without any damage.

Public office 1234 Lincoln Street	Santa Monica	Detail of URM damage and roof system with timber members (Office in Lincoln #1231)
Public office 1235 Lincoln Street	Santa Monica	Detail of insufficient clear space between office and neighbor bldg.
Harman Industries Wilshire and 9th Street: South East corner	Santa Monica	URM structures with shear cracks from the arc opening to the upper left corner. Double height one-story building.
Memory Flowers Wilshire and 11th Street SE corner	Santa Monica	One-story commercial building with R/C structural system. Damage was observed in URM parapet which supports the old roof system.
Memory Flowers Wilshire and 11th Street SE corner	Santa Monica	Corner view of the commercial store. Out of plane failure in URM parapet.
Memory Flowers Wilshire and 11th Street SE corner	Santa Monica	Damage in URM parapet of the commercial store.
Santa Monica Imaging Center Wilshire 1131 and 12th Street NW corner	Santa Monica	Three-story R/C structure private building. Local damage in left end of beam.
Santa Monica Imaging Center Wilshire 1131 and 12th Street NW corner	Santa Monica	General view of the building
Santa Monica Imaging Center Wilshire 1131 and 12th Street NW corner	Santa Monica	Flexural and shear cracks in left end of the beam. At the bottom of the column only the finish cover spalled off.
Commercial building Wilshire and 14th Street SE corner	Santa Monica	Two-story commercial URM structure. Shear cracks in transverse walls of the second story which have openings. Also slip failure in walls was observed.
Commercial building Wilshire and 14th Street SE corner	Santa Monica	General view of the commercial building along Wilshire Street.
Commercial building Wilshire and 14th Street SE corner	Santa Monica	Transverse walls and window openings in the second story.
Commercial building Wilshire and 14th Street SE corner	Santa Monica	Shear cracks in the second story of the transverse walls from opening to upper right corner.
Santa Monica Hospital 15th Street near Wilshire	Santa Monica	R/C building with coupled shear walls, eight stories maybe 20 years old. Shear failure of coupling beams on N side. Uplift of SW corner wall, significant cracking, coupling beam shear failure torsional damage.

Santa Monica Hospital 15th Street near Wilshire	Santa Monica	General view of the hospital and shear failure in coupling beams is observed.
Santa Monica Hospital 15th Street near Wilshire	Santa Monica	Details of shear damage in coupling beams
Santa Monica Hospital 15th Street near Wilshire	Santa Monica	Damage in the lower part of the neighbor building URM wall severe damage in finish and wall.
Santa Monica Hospital 15th Street near Wilshire	Santa Monica	Detail of damage due to no separation between the hospital (8 stories) and the neighbor building (3 stories). Pounding between two structures.
Santa Monica Hospital 15th Street near Wilshire	Santa Monica	Back side of Santa Monica Hospital. Shear cracks in concrete walls near windows openings.
Barkley East Convalescent Hospital	Santa Monica	5-story RM building. Shear cracks on the 3rd story crossing from the upper left corner of window openings throughout slab or collar beam.
Barkley East Convalescent Hospital	Santa Monica	Front view of the hospital and shear cracks of masonry walls located at the top of the openings on the 3rd floor.
Medical Center of Santa Monica 2021 Santa Monica Bl and 20th St (N corner)	Santa Monica	Two main towers are a 7-story and a 12-story R/C buildings. No structural damage noted.
Parking Building of the Medical Center of Santa Monica Arizona Av between 20th and 21st Streets	Santa Monica	Three-story R/C frame structure with post-tensioned girders. One-way sląb and R/C walls. Columns had a square section with a circular core with spiral reinforcement. The building shows more damage in the NE-SW direction. At ground level severe concrete spalling and shear cracking was observed. Column height and width were 2.0 m and 55 cm, respectively.
Parking building of the Medical Center of Santa Monica Arizona Av. between 20th. and 21 Streets.	Santa Monica	General view of the frame structure and RC masonry parapets
Parking Building of the Medical Center of Santa Monica Arizona Av between 20th and 21st Streets	Santa Monica	Shear cracks at the top of the column in the 1st story.
Parking Building of the Medical Center of Santa Monica Arizona Av between 20th and 21st Streets	Santa Monica	Spalling of concrete cover near the slab-column connection.
Parking Building of the Medical Center of Santa Monica Arizona Av between 20th and 21st Streets	Santa Monica	Spalling and shear cracking of column because of short-column effect due to a R/C spandrel wall. The spiral reinforcement seems to be adequate.

Parking Building of the Medical Center of Santa Monica Arizona Av between 20th and 21st Streets	Santa Monica	Square R/C column with small damage in the beam-column joint (flexural cracks).
Parking Building of the Medical Center of Santa Monica Arizona Av between 20th and 21st Streets	Santa Monica	Flexural cracks at the external face of a beam-column connection.
Apartment building	Santa Monica	Medium rise RM building (maybe 5-story building), shear cracks above the window opening in the collar RM beam.
Apartment building	Santa Monica	Facade of the building without any kind of damage.
Apartment building	Santa Monica	Big shear cracks at the corner column in the first story.
Office Building 2020 Santa Monica Bl and 20th Street	Santa Monica	Six-story steel frame structure with R/C jacketing and R/C walls. Walls are located in all four facades. Shear cracking columns was observed. Column effective height was reduced by a parapet for spandrel wall. Wall cracking and crushing were visible. The building was in normal operation since a structure engineering firm had checked the structural safety. A letter from this office was posted at the building entrance.
Office Building 2021 Santa Monica Bl and 20th Street	Santa Monica	General view of an office building composite structure.
Office Building 2022 Santa Monica Bl and 20th Street	Santa Monica	Front view of the office bldg. No damage in this side.
Office Building 2023 Santa Monica Bl and 20th Street	Santa Monica	Flexural and shear damage in R/C wall, buckling of rebars at the right end of the wall.
St. John's Hospital Santa Monica Bl and 21st Street	Santa Monica	Six-floor plus pent-house R/C structure. Shear cracking only in the N facade in columns and wall piers at the second floor (above ground level). Stiffness and strength were irregular in this story compared with other floors. Tie spacing was 20 cm.
St. John's Hospital Santa Monica Bl and 21st Street	Santa Monica	Severe shear cracks in the N facade in columns and wall piers at the second story.

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