BRIEF REPORT ON THE JANUARY 17 1994 NORTHRIDGE EARTHQUAKE IN LOS ANGELES

SUMMARY

An earthquake struck the San Fernando Valley on January 17 at 4:30 am. Pacific Standard Time. The epicentre was located at 34° 13' North, 118° 3' West at a depth of 14.6 km. The surface wave magnitude from the National Earthquake Information Centre was 6.6. The local magnitude was 6.4.

Most of this information was prepared within a few days of the earthquake occurring and some of the material included in this report was issued as a press release.

A more detailed report is currently being prepared by the Reconnaissance Team sent by the Society.

INTRODUCTION

The magnitude 6.6 earthquake - now called the *Northridge Earthquake* - occurred at 4:30 a.m. on January 17, 1994. The causative fault slip was just to the west of the slip that generated the 1971 San Fernando earthquake. However, at this time, geologists are uncertain whether this was an overthrust like 1971 or an underthrust fault slip. The earthquake centred on the northern boundary of the city of Los Angeles which has been much developed since 1971. The earthquake generated 29%g peak acceleration in downtown Los Angeles approximately 30 kilometres south of the fault. A six-story parking structure had 1.21g on the roof and 0.29g on the ground. The earthquake was very similar to the 1971 San Fernando event but perhaps slightly larger. Damage was very similar to San Fernando. Several freeway bridges that had been constructed prior to 1971 and not yet retrofitted, collapsed during this earthquake. The first story of a three-story apartment building collapsed and killed 15 people. Several parking structures collapsed and a store building was severely damaged. Figure 1 (published in several NZ newspapers the following day), summarises some of the immediately available information about tha cause of the earthquake and the resulting damage.

Collapse and serious damage occurred to deficient structures and there was no evidence that modern well-built structures were in danger of collapse. Significant damage was sustained only by buildings in the near-field of the earthquake, though in a few cases damage at greater distances was sustained by inadequate structures. The area of damaging shaking was approximately a circle of 10 miles radius (the northern part of the circle included mountainous regions). A notable case of soil liquefaction occurred at Redondo Beach approximately 20 miles south of the causative fault.

Ninety percent of the metropolitan Los Angeles area was not affected by damaging ground shaking. Estimates of damage have been placed at approximately $7,000,000,000. This was not the big earthquake that we expect on the San Andreas fault.

Caltech was not damaged.

FAULT ORIENTATION

The two planes of the focal mechanism of the earthquake both strike slightly north of east and show almost pure reverse motion. One dips 60 degrees to the south, and the other dips 30 degrees to the north. Which is the causal fault is still uncertain. The main shock's epicentre is several kilometres south of the southern end of the rupture zone of the 1971 San Fernando earthquake (magnitude 6.6). Most of the aftershocks of the Northridge earthquake are located to the north of the mainshock with relatively unconstrained depths. Because of the lack of depth control, we cannot at this point discriminate between a shallowly north dipping plane with the aftershocks downdip from the mainshock and a steeply south dipping plane with the aftershocks updip from the mainshock. The main shock occurred at the approximate depth predicted for the Santa Monica Mountains extension of the Elysian Park fold and thrust belt. A small part of the Elysian Park fold and thrust belt broke in the 1987 Whittier Narrows earthquake. Portable seismographs have been deployed to improve the depth control of the aftershocks and help resolve which fault caused this earthquake.

SURFACE RUPTURE

The first thirty-six hours after the earthquake were spent by USGS geologists in gathering geological information relevant to understanding the earthquake. From their initial field reconnaissance, they concluded that no major surficial fault rupture occurred. At that stage, no reports had been received from other geologists in the field that contradicted their initial assessment. This lack of obvious expression contrasts sharply with the 15 km long surficial rupture that accompanied the 1971 San Fernando earthquake. In this respect it is, however, very much like the 1987 Whittier Narrows, 1989 Loma Prieta and 1991 Sierra Madre earthquakes.

One small zone of disturbance that was verified by USGS and Caltech geologists on the ground appears to be the result of motion along a fault. This few hundred metre long system of cracks runs nearly east-west across Balboa Blvd, north of

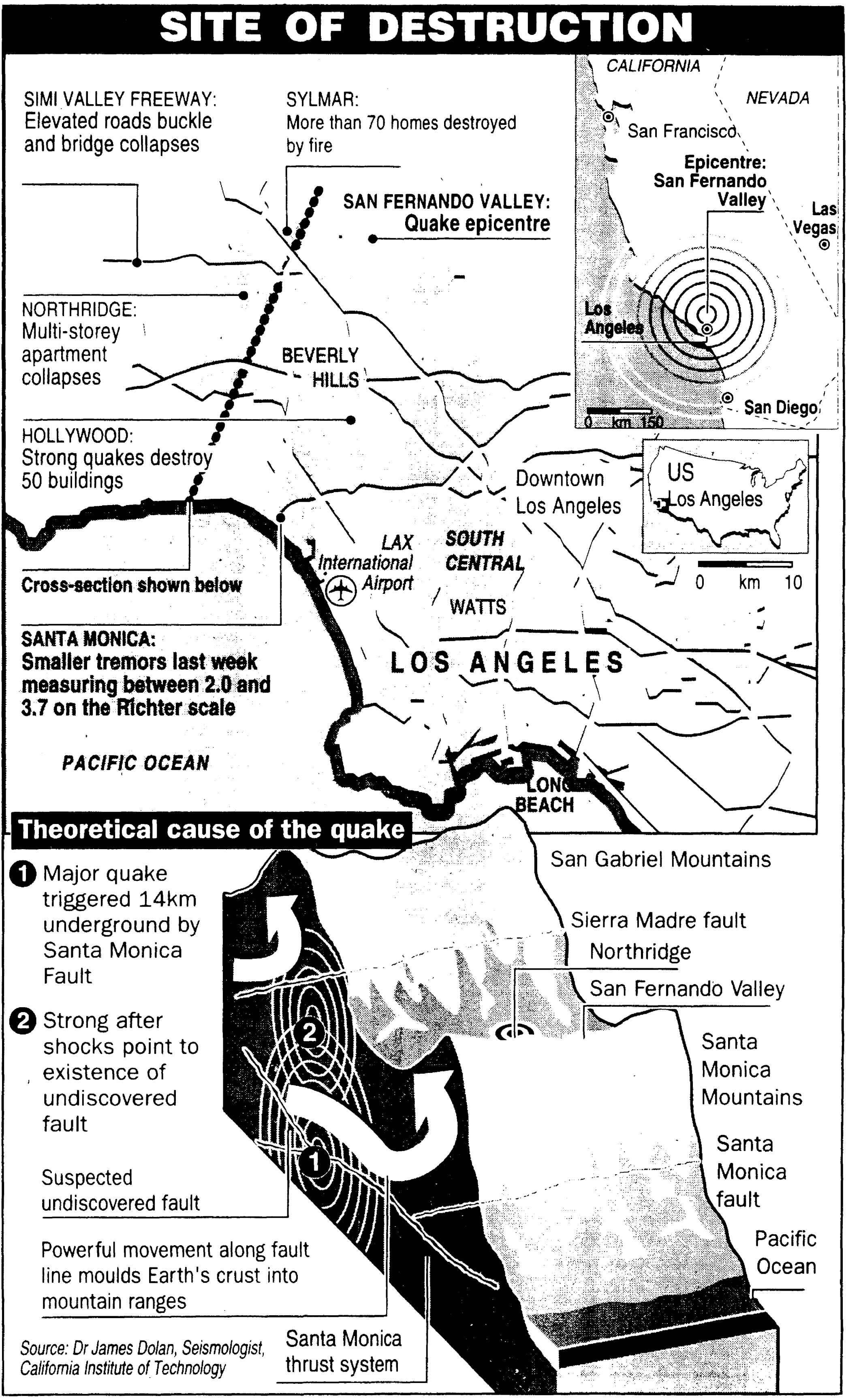


Figure 1 Newspaper summary of damage and the cause of the earthquake.

the Simi Valley freeway. Its location and orientation suggest that it is the result of minor movement along the Mission Hills Fault. Movement of the fault resulted in major disruptions of water and gas pipelines. Seismographic information indicates that the fault that produced the earthquake lies many kilometres beneath the northern San Fernando Valley. It is either a steeply inclined structure that dips south or a shallowly inclined structure that dips north. Aftershock depths are still too poorly constrained to conclude with certainty that the steep south-dipping plane is the fault that produced the earthquake, but this interpretation was favoured pending further information.

A south-dipping plane would be consistent with south-dipping faults known from oilfields in the northern San Fernando Valley. These faults appear to be part of a system of south-dipping faults that are being called the Oakridge fault system. Well data indicate, however, that these faults have not moved near the surface for at least the past half million years. This does not tell us whether they broke at depth. It is consistent with the lack of surface rupture in this event.

STRONG MOTION RECORDS

The first strong-motion records available from CSMIP (California Strong Motion Instrumentation Program) stations indicated shaking of 0.25-0.50 g in the Los Angeles area, with the strongest shaking in the North-South direction. Figure 2 shows the location of the epicentre and selected CSMIP stations while the unnumbered figures that follow show the records obtained from several structures together with the location of the accelerometers on each structure. Table 1 lists the epicentral distance and peak acceleration values for a number of the over 175 CSMIP stations that were expected to have recorded the event. The closest stations were in the Van Nuys, Sherman Oaks and Burbank areas.

A few record highlights are:

- **Tarzana - Cedar Hill Nursery**. The closest free field CSMIP station, approximately 7 km from the epicentre, recorded a peak horizontal acceleration of 1.82 g, and a vertical acceleration of 1.18 g.

- **Arleta - Nordhoff Ave Fire Station**. The second closest free field CSMIP station, approximately 9 km east of the epicentre, recorded a peak horizontal acceleration of 0.35 g, but a higher vertical acceleration of 0.59 g.

- **Sylmar - 6 storey County Hospital**. Large accelerations were recorded during the earthquake, as high as 0.82 g at the base. This structure replaced the hospital that collapsed in the 1971 San Fernando earthquake. An acceleration as high as 2.3 g horizontal was recorded at the roof level.

- **Los Angeles - I10/405 Interchange**. A freeway interchange located approximately 23 km from the epicentre. Peak accelerations of 1.0 g and greater were recorded on the structure near the west abutment. This structure is located about 6 km west of the section of the I10 Freeway that collapsed during the earthquake and was recently instumented in cooperation with Caltrans.

AFTERSHOCK PROBABILITIES

Aftershocks --- What to Expect

Earthquakes occur in clusters. One of the first things recognized about earthquakes is that large events hardly ever occur alone. When one earthquake happens, we usually see another at a nearby or identical location. To be able to talk about this phenomena seismologists have coined three terms - "foreshock", "mainshock", and "aftershock". In any cluster of earthquakes, the one with the largest magnitude is called the mainshock; anything before it is called a foreshock and anything after it is called an aftershock. A mainshock can turn into a foreshock if a subsequent event comes along with a larger magnitude.

Earthquakes happen over an area of a fault called the rupture-surface. Because of friction, when the rocks on each side of the fault are pushed sideways, they do not slip immediately. Eventually enough strain is built up and the rocks slip suddenly, releasing energy in the form of sound waves and shear waves that travel through the rock to cause the shaking that we feel as the earthquakes. Forget what your high school science books said about earthquakes happening at a "focus." The focus (seismologists use the term hypocentre, epicentre is the point on the Earth's surface above the hypocentre) is only the point where the earthquake starts. The rupture begins at that point and then spreads down the fault. It keeps moving down the fault until it runs into something that stops it (exactly how this happens is one of the hot research topics in seismology). Because each point on that surface radiates energy, the bigger the fault's rupture surface, the bigger the earthquake.

Clustering of earthquakes usually occurs only very near the location of the mainshock. The rupture surface that moves in the mainshock experiences a great redistribution of the stress on it during the main shock and it is that disrupted surface that produces most of the aftershocks. Sometimes the change in stress in the mainshock is great enough to trigger aftershocks on nearby faults. However, the stress change dies off quickly with distance from the fault so we rarely see aftershocks more than a few kilometres from the main fault. As a rule of thumb, seismologists say that aftershocks are other earthquakes triggered at a distance from the mainshock fault that is no greater than the length of that fault.

Bigger earthquakes have more and larger aftershocks. As the magnitude of the mainshock increases the magnitude of the largest aftershock, on average, increases as well. The difference in magnitude between the mainshock and largest aftershock can range from 0.1 to 3 or more, but averages 1.2 (a M5.5 aftershock to a M6.6 mainshock for example). Below that, the number of aftershocks at each magnitude level goes up as the magnitude of the aftershock goes down. On average, for each magnitude 5 aftershock in a sequence, we will see 10 magnitude 4 aftershocks, 100 magnitude 3 aftershocks, 1000 magnitude 2 aftershocks, etc.

In general, an earthquake large enough to cause damage will produce several felt aftershocks within the first hour. The rate of aftershocks dies off quickly with time so even the second day will have many fewer aftershocks than the first. The daily rate of aftershocks is proportional to the inverse of time since the mainshock. Thus the tenth day after the mainshock will have approximately 1/10 the number of

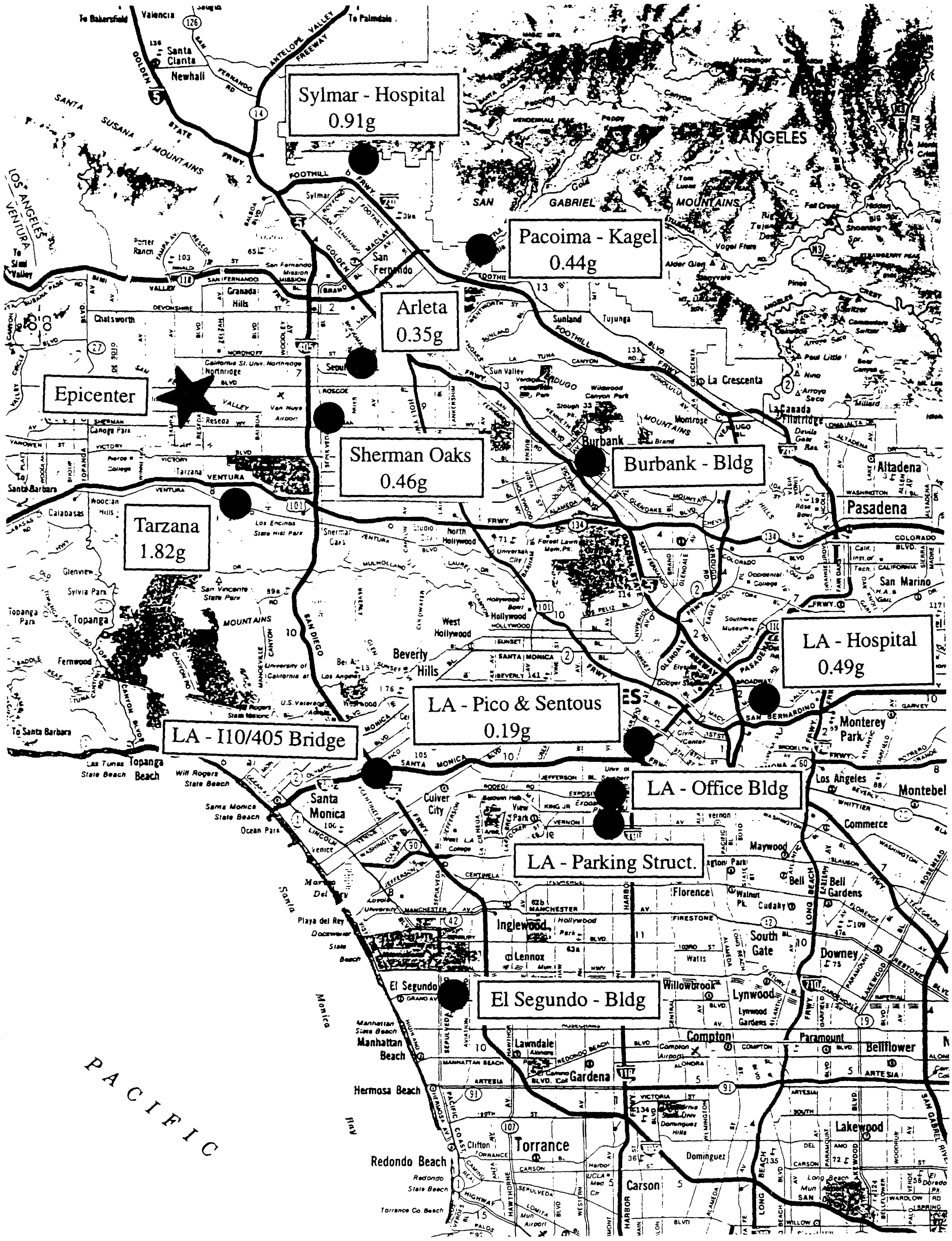


Figure 2 *Map of the Los Angeles area showing selected CSMIP stations (circles) that recorded the 17 January 1994 earthquake in the San Fernando Valley.*

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[1]	Maximum Acceleration		
					Free-field	Base	Structure
24386	Van Nuys - 7 storey Hotel	34.221	118.471	6 km	---	0.47g h 0.30g V	.059g 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 storey Commercial Bldg	34.154	118.465	10 km	---	0.46g H 0.18g V	0.90g H
24514	Sylmar - 6 storey 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 St. #74	34.288	118.375	17 km	0.44g H 0.19g V	---	---
24207	Pacoima Dam	34.334	118.396	18 km	---	0.54g H 0.43g V	>2.3g H >1.7g V
24464	North Hollywood - 20 storey Hotel	34.138	118.359	19 km	---	0.33g H 0.15g V	0.66g H
24231	Los Angeles - 7 storey University Building	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 storey Office Building	34.059	118.416	21 km	---	0.32g H 0.13g V	0.65g H
24385	Burbank - 10 storey Residential Bldg	34.187	118.311	21 km	---	0.30g H 0.13g V	0.79g H
24370	Burbank - 6 storey Commercial Bldg	34.185	118.308	22 km	---	0.25g H 0.15g V	0.49g H
24670	Los Angeles - I10/405 Interchange Bridge	34.031	118.433	23 km	---	---	1.00g H 1.83g V
24303	Los Angeles - Hollywood Storage Building Free Field	34.090	118.339	23 km	0.41g H 0.19g V	---	---
24236	Los Angeles - Hollywood Storage Building	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 Dam	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	---	---
24602	Los Angeles - 52 storey Office Building	34.051	118.259	32 km	---	0.15g H 0.11g V	0.41 g H
24611	Los Angeles - Temple and Hope	34.059	118.246	32 km	0.19g H 0.10g V	---	---
24655	Los Angeles - 6 storey Parking Structure	34.021	118.289	32 km	---	0.29g H 0.22g V	1.21g H 0.52g V

TABLE 1: (cont.)

No.	Station Name	N.Lat	W.Long	Epicentral Distance[1]	Maximum Acceleration		
					Free-field	Base	Structure
24629	Los Angeles - 54 storey Office Building	34.048	118.260	32 km	---	0.14g H 0.08g V	0.19g H
24652	Los Angeles - 6 storey Office Building	34.021	118.287	32 km	---	0.24g H 0.08g V	0.59g H 0.18g V
24569	Los Angeles - 15 storey Govt Office Bldg	34.058	118.249	32 km	---	0.21g H 0.07g V	0.29g H
24579	Los Angeles - 9 storey Office Building	34.044	118.261	32 km	---	0.18g H 0.12g V	0.34g H
24283	Moorpark	34.288	118.881	33 km	0.30g H 0.15g V	---	---
14654	El Segundo - 14 storey Office Building	33.920	118.390	36 km	---	0.13g H 0.04g V	0.25g H 0.17g V
24605	Los Angeles - 7 storey 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
24541	Pasadena - 6 storey Office Building	34.146	118.147	37 km	---	0.17g H 0.09g V	0.21g H
24468	Los Angeles - 8 storey 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
24401	San Marino - Southwestern Academy	34.115	118.130	39 km	0.16g H 0.09g V	---	---
14606	Whittier - 8 storey 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 storey 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
14578	Seal Beach - 8 storey Office Building	33.757	118.084	66 km	0.09g H 0.04g V	0.08g H 0.03g V	0.15g H 0.16g V
23622	San Bernardino - 1 storey Commercial Bldg	34.098	117.293	115 km	---	0.05g H 0.02g V	0.15g H
23631	San Bernardino - Hwy I10/215 Free Field	34.065	117.292	115 km	0.10g H 0.04g V	---	---
23631	San Bernardino - I10/215 Interchange	34.064	117.296	115 km	0.10g H 0.04g V	0.13g H 0.04g V	0.47g H 0.31g V
12636	Sage - Fire Station	33.580	116.931	165 km	0.03g H 0.02g V	---	---

---

[1] Distance from estimated epicentre at 34.219N, 118.538W.

aftershocks that the first day had. Seismologists call an earthquake an aftershock as long as the rate at which earthquakes are occurring in that region is greater than the rate seen before the mainshock. How long that will be depends on the size of the mainshock (bigger earthquakes have a higher rate of aftershocks so it stays above background longer), and how active the region was before the mainshock (if it was quiet, the aftershocks stay noticeable longer).

The relative number of small to large aftershocks does not appear to change with time. However, since the overall rate dies off, all magnitudes become less common with time. Since small magnitudes happen much more often, we have more of them later. But all magnitudes die off at the same rate - magnitude 5s are 1/10 as common on day 10 as day 1, and magnitude 4s are 1/10 as common on day 10 as day 1.

It is also possible that the first earthquake will turn out to be a foreshock to an even larger event (this happens 6% of the time in California). Like aftershocks, the chances of this happening also die off quickly. The most likely time for a mainshock is within the first hour (one-quarter of all mainshocks happen within an hour of their foreshock) and after three days the risk is almost gone.

Aftershocks to the Northridge Earthquake

The aftershocks to the Northridge earthquake are following a very regular pattern - almost exactly average for what is expected in a California aftershock sequence. As of 3:30 p.m. on Wednesday, January 19, 1994, 4 aftershocks of magnitude 5.0-5.3 were recorded, 23 aftershocks between magnitude 4.0-4.9, and 202 aftershocks between magnitude 3.0-3.9. The magnitude distribution is normal.

The aftershocks are decaying as expected. The chance of another magnitude 5 in the next week has decreased as time has passed to about 1 in 3 *(i.e. at the time of writing - Editor).* The chance of a more damaging magnitude 6 is lower. More felt aftershocks are sure to happen but will decrease with time.

Technically, the rate of aftershocks is

$$rate \;=\; 10^{(a-b(M-Mm))} * (t+c)^{-p}$$

where M is the magnitude of the aftershock, Mm is magnitude of the mainshock, t is the time since the mainshock and a, b, c, and p are constants. Once you determine these constants you have a rate and with a rate, you have a probability. The constants in California have been about normally distributed and the average values are the "generic" aftershock sequence.

Right after an earthquake, the generic earthquake is used to estimate probabilities. Notice the role of the mainshock magnitude - bigger earthquakes have many more aftershocks. As the sequence is recorded, it is possible to estimate the parameters for that sequence. To date, it has been found that the Northridge sequence is very close to average; p = 1.07 (exactly generic), b = 1.0 (generic b = 0.9), c = 0.07 (generic c = 0.05) and a = -1.45 (generic a = -1.7). The most noticeable variation is a slightly high value for a, although even that is not a big difference. It is well within 1 standard deviation.

ULTRA-LOW FREQUENCY MEASUREMENTS.

The STAR lab at Stanford University has two seismometer systems operating close to two different segments of the San Andreas fault in Southern California that are clearly operating very well, with complete consistency between their measurements and those of the Corralitos system in Northern California.

Did they detect any precursors to the Southern California earthquake? "We are not sure at this moment. Clearly there was nothing very big. Unfortunately, as others can probably confirm, a period of enhanced ultra-low frequency (ULF) solar-induced activity (magnetic storm) started on 11 January and continues on our records through to the present. This reduces the sensitivity of our measurements and we cannot say for sure that we saw no ULF signals before the earthquake until we have had time to process out the magnetic storm signals, but clearly there is nothing big immediately evident on the Southern California records. (I hope no one will claim that the period of magnetic storm was a precursor to the earthquake, but I fear the worst).

"Our nearest station to Northridge is at Table Mountain, 80 km (50 mi) away. Good data, with no big signals that don't also appear on the Corralitos records as well and which therefore are not earthquake related as far as we are concerned. In USGS Professional Paper 1550-C, p. C23, I estimated that the Loma Prieta signals we measured 'might have been measurable out to a distance of about 100 km from the epicentre'. That is from a M7.1 (and a strike/slip fault). Under the circumstances, I would not expect any big signals, and possibly no detectable signals, at a location, about 80 km away from a M6.6. Maybe a thrust fault could generate something different, but we don't know.

"Believe it or not, I'm very happy with the way these results are coming along. We have some real data, some good measurements - even some consistency.

"Interestingly, a co-seismic shaking response to the Southern California earthquake shows up very nicely on the two Southern California systems and also at Parkfield! Hugo Benioff (a Caltech earthquake pioneer who looked into the use of coil sensors for earthquake detection as a form of seismometer) would be very pleased. Nothing at Corralitos though, which is the furthest away of these instruments".

DAMAGE SUMMARY

Ground Failures

The Northridge earthquake caused ground failures at several locations within the San Fernando Valley and in the Los Angeles basin from Highway 126 in the north to the Port of Los Angeles in the South. Although these phenomena were concentrated mainly in the epicentral region, incidents of ground failure or ground deformation did occur at distances of up to 36 miles from the epicentre.

Soil Liquefaction and Lateral Spreading

Evidence of soil liquefaction including sand boils, ground settlement, and lateral spreading was found over a fairly widespread area (see Figure 3). Damage associated with liquefaction generally included the breakage of buried

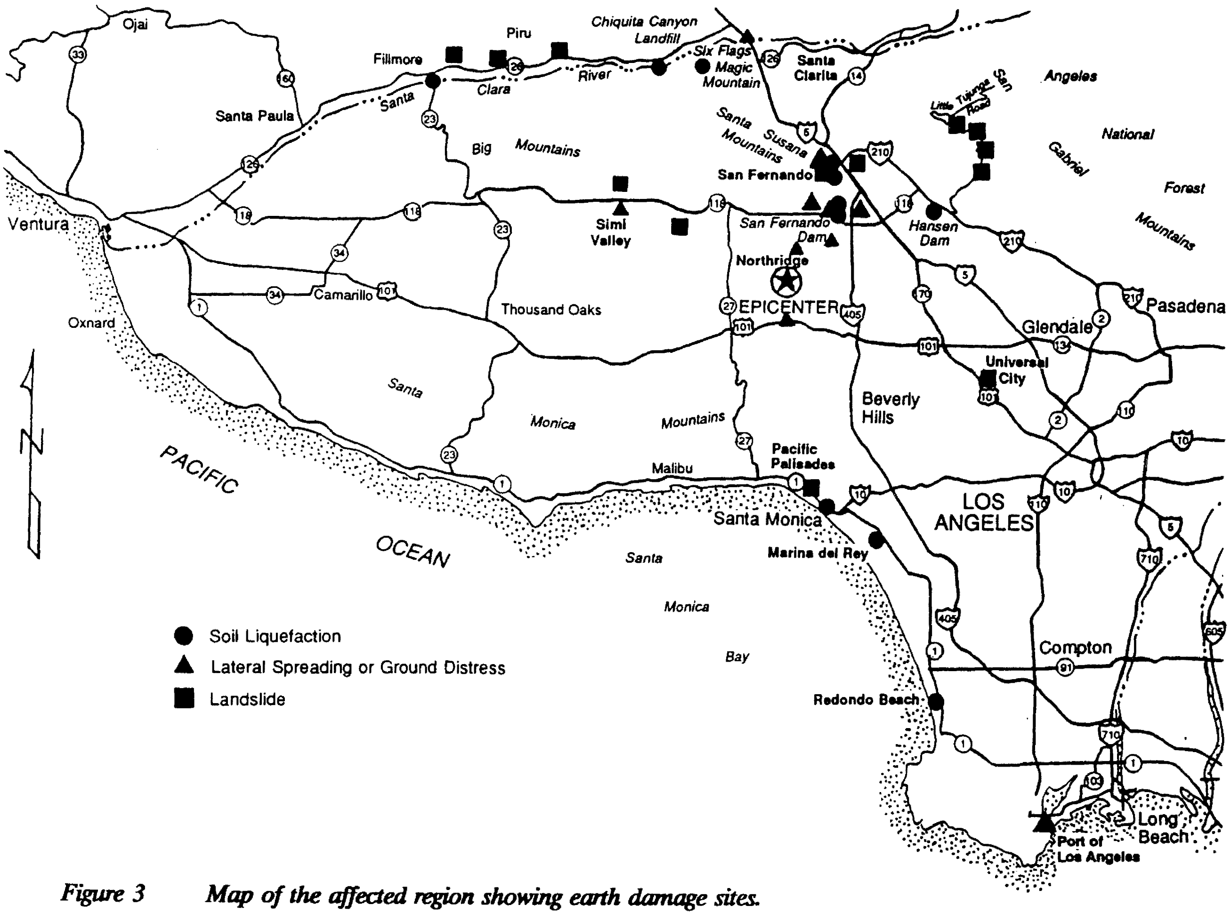


Figure 3 *Map of the affected region showing earth damage sites.*

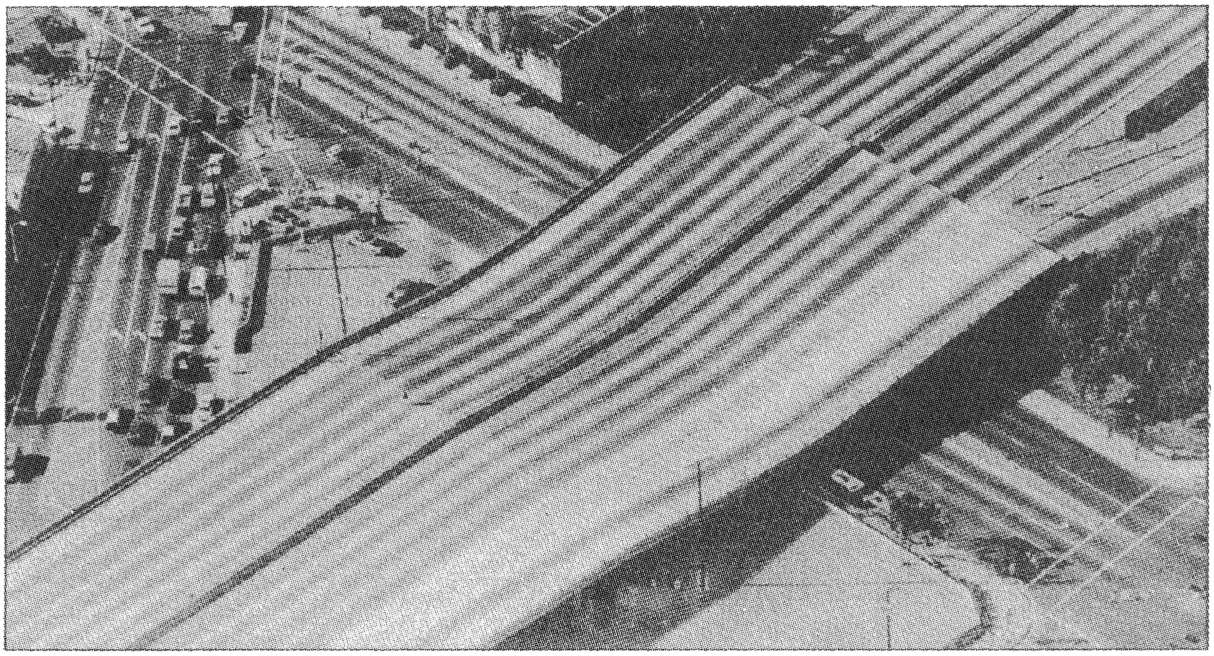


Figure 4 *A section of the Santa Monica Freeway collapsed onto La Cienega Boulevard (Timaru Herald)*

pipelines and pavement cracking/buckling. Based on the preliminary results of their reconnaissance, the Earthquake Engineering Research Center team (1994) concluded that liquefaction does not appear to have directly contributed to any structural failures of buildings or highway structures, and was a relatively minor factor compared to the strong shaking that caused damage to structures in most areas. Much of the "lateral spreading" damage noted by the EERC team in urban areas appeared to have resulted either from minor liquefaction at depth, with non-liquefied soils largely mitigating surface distress, or from cyclic compaction of non-saturated alluvium.

Landslides

Scattered minor rockfalls and landslides occurred throughout Los Angeles and Ventura Counties (see Figure 2). Major landslides occurred in the Santa Monica and San Gabriel Mountains closing roads and destroying homes. In addition, shattered ridges were observed in the Santa Susana Mountains, north of the epicentral region.

The most damaging landslides occurred in the coastal bluffs of the Pacific Palisades in Santa Monica (Figure 2). Here, the northbound lanes of the Pacific Coastal Highway remained closed for at least four days following the earthquake. Four large landslides occurred in this area, along with several small slides.

Earth Structures

A total of nine earth or rockfill embankment dams were inspected by the EERC team. The California Division of Safety of Dams (DSOD) has undertaken an intensive inspection of all major dams within the strongly shaken region.

A number of dams suffered relatively minor cracking. The Upper Van Norman Lake dam experienced minor cracking along the crest of the embankment. About twenty feet down the west side of the downstream face, three to four inches of settlement was observed around what appeared to be concrete "mini-piles", about two to three inches in diameter. The eastern portion of the downstream face experienced moderate cracking with less cracking towards the western end of the embankment.

The asphalt lining of the storage reservoir at the DWP water treatment facility cracked at several locations, with one crack extending below the water level. There were also some broken pipes at the crest of the reservoir, but the EERC team were not able to determine if the earthquake caused these breaks.

Of the several earth and/or rockfill dams that experienced minor cracking and distress, several suffered damage to their abutments and and/or reservoir slopes. Details will presumably be made available later by the DSOD. Similarly, the Pacoima Dam (a concrete structure) suffered damage very similar to that suffered in 1971. Peak accelerations of about 2g horizontally and vertically were recorded at both the crest and an abutment station at Pacoima Dam (see Table 1).

Overall, no major dams or embankments suffered significant damage posing any threat of failure and the performance of dams was generally good.

Solid Waste Landfills

The earthquake provided important observational data on the response of landfills to strong levels of earthquake shaking. A large number of landfills in the Los Angeles area were located close to the epicentre and experienced strong levels of shaking, being subjected to peak bedrock (input) accelerations of 0.2g to 0.5g. Nine of these were inspected after the earthquake. Although no landfills demonstrated any signs of a major instability, several experienced minor levels of damage (cracking).

Transportation Structures

The metropolitan Los Angeles area is highly dependent on its transportation systems. Most of the 600 mile freeway system survived the Northridge earthquake with minimal or easily repairable damage. However, the extensive damage or collapse of eleven freeway structures caused widespread disruption after the earthquake (see Figures 4 - 6). Structures retrofitted by Caltrans since the 1989 Loma Prieta earthquake performed very well in most cases. Structures designed to current standards appear to have performed well, indicating that if the damaged structures had been designed to current standards many of the observed failures would not have occurred.

Howver, an article in *New Civil Engineer* states that severe doubts are being expressed over the adequacy of California's bridge retrofitting programme. Engineers examining the hundreds of damaged smaller bridges are reported to have admitted that the most widely used retrofitting system - cable joint restraints - has failed in several cases, despite official claims that the upgrade programme had proved a success. If this is true, then hundreds of already retrofitted bridges would need to be further strengthened.

Building Structures

Reinforced Concrete Buildings

These suffered significant structural damage. Two buildings suffered partial collapse, while another suffered such seriuos structural damage that it had to be demolished immediately. All types of structural systems from ductile frames, shear walls, coupled shear walls and dual systems to non-ductile reinforced concrete frames suffered structural damage.

Parking Structures

Parking buildings represent the category of modern engineered structures that appeared to have suffered the largest incidence of partial or total collapse cases. These occurred both in the immediate vicinity of the epicentre, with several spectacular failures in the Northridge Fashion Island Mall and on the campus of the California State University at Northridge (CSUN), and also at a distance from the epicentre, with failures of the parking structures in the Glendale Civic Centre (two), at the Kaiser Permanente in Culver City (two) and in Santa Monica.

Unreinforced Masonry Buildings

These have long been identified as buildings prone to severe structural and non-structural damage in moderate and and strong ground motions. Extensive damage was evident in the preliminary EERC reconnaissance survey. Of particular

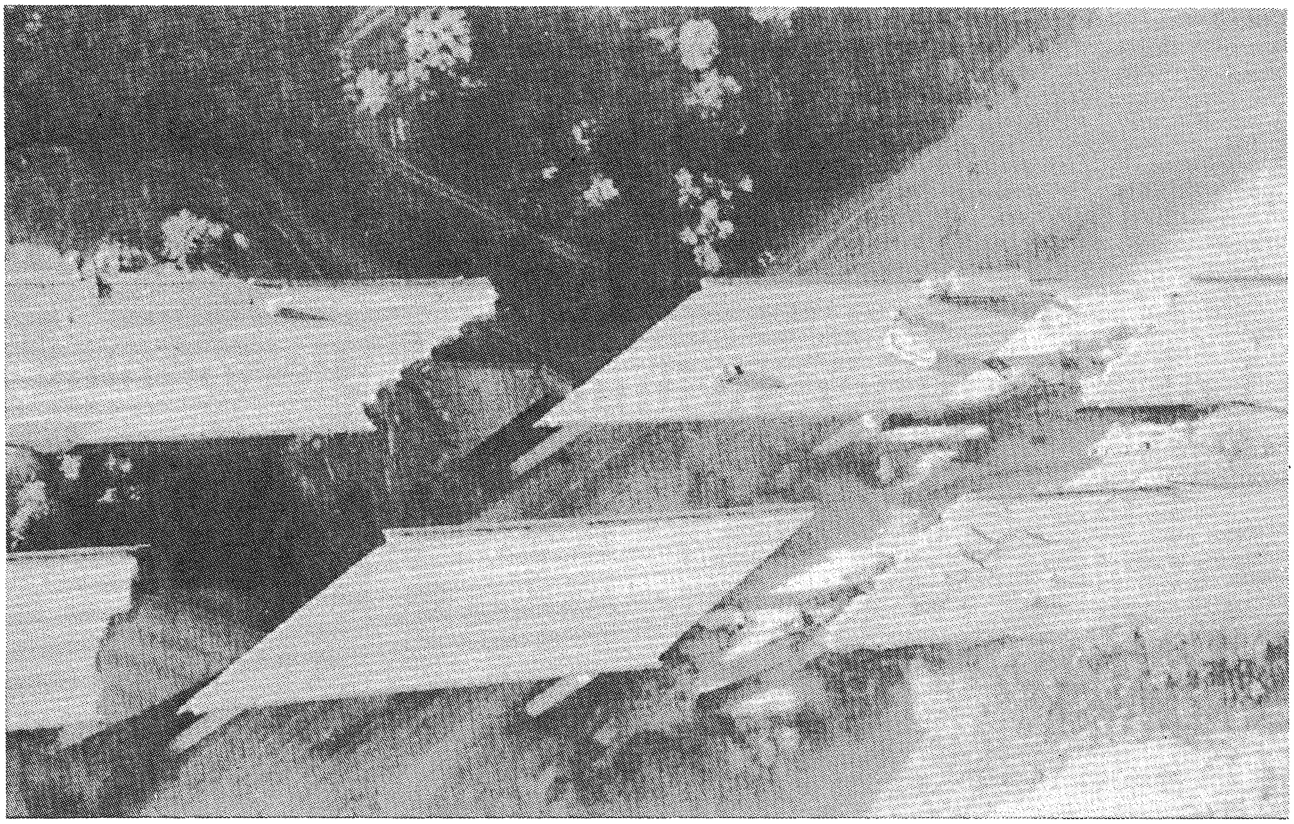


Figure 5 *Vehicles are stranded on the centre section of a bridge on Interstate Five (Reuter/Christchurch Press).*

Figure 6 *Collapsed Freeway overpass (Reuter/Christchurch Press).*

interest was that several buildings in the area of strong shaking had been retrofitted in accordance with the earthquake risk mitigation program for URM buildings that was adopted by the City of Los Angeles in 1981. While the EERC team were not able to identify in the short time available to them, which buildings had been retrofitted and which had not, some instances of damage to retrofitted URM buildings were observed.

Hospitals

Much as in the 1971 San Fernando earthquake, several hospitals in the area of strong shaking suffered structural and very serious non-stuctural damage. The Indian Hills Hospital suffered structural damage in the shear walls with concrete crushing and apparent lap splice failure at he construction joint at the fourth floor level. The Veterans Hill Hospital in the immediate vicinity of the epicentre suffered very serious damage to contents and equipment. Water from the ruptured sprinkler system ran for several hours and flooded a good portion of the building according to preliminary reports. Severe structural damage at the St. John's Hospital in Santa Monica caused its immediate evacuation.

Of particular interest to earthquake engineers is the fact that the Olive View Hospital which was rebuilt after its collapse following the 1971 San Fernando earthquake recorded a peak horizontal acceleration of 2.3g in the mechanical services penthouse at the roof level, but did not suffer serious damage.

Residential Structures

Most residential structures in the vicinity of the epicentre were one storey timber houses and two to three storey timber apartment buildings. Single storey houses appeared at this stage to have suffered little damage. Several chimneys broke at the roof line and fell, while several buildings were displaced horizontally from their foundations due to inadequate anchorage.

By contrast, two to three storey apartment buildings in the vicinity of the epicentre suffered extensive structural damage and several first floor (ground floor in New Zealand terminology) partial or full collapses were responsible for the majority of deaths in the Northridge earthquake. Most apartment buildings in the epicentral area were poorly engineered timber frame buildings covered with stucco walls only and lacked a lateral load resisting system due to the absence of plywood shear walls. Most of these buildings had carports in the ground floor with apartments located on the floors above. This lead to a large number of soft first storey collapse mechanisms. In one instance, part of the ground floor was also filled with apartments and gave rise to the highest single incidence of deaths.

Base Isolated Structures

Three seismically-isolated structures in the Los Angeles area were subjected to strong ground shaking during the Northridge earthquake. Two of these are supported on elastomeric isolators - the University of Southern California Teaching Hospital (USC) and the Los Angeles County Fire Command and Control Facility (FCCF) - while the third is supported on a helical steel spring and viscous dashpot system (GERB). Preliminary accelerograms have been released by the California Strong Motion Instrumentation Program (CSIMP) from the USC (see Figures of accelerograms) and FCCF buildings. The USGS has recently recovered accelerograms from the GERB structure, but these have yet to be made available.

ACKNOWLEDGEMENTS

This report has been compiled from information received from a number of sources including Prof. Housner, California Institute of Technology, the Caltech Seismological Observatory, the US Geological Survey, Pasadena, the STAR Laboratory, Stanford University, and the Earthquake Engineering Research Center at the University of California at Berkeley.

REFERENCES

Moehle, J.P. (Ed.), (1994), "*Preliminary Report on the Seismological and Engineering Aspects of the January 17, 1994 Northridge Earthquake*", Report No. UCB/EERC-94/01, Earthquake Engineering Research Center, College of Engineering, University of California at Berkeley, Richmond, California, USA, January 24.

State of California, Division of Mines and Geology, Strong Motion Instrumentation Program (CSMIP),(1994), "*First Quick Report on CSMIP Strong-Motion Data from the San Fernando Valley earthquake of Jan 17, 1994*", *Report OSMS 94-01*, California Strong Motion Instrumentation Program (CSMIP).

State of California, Division of Mines and Geology, Strong Motion Instrumentation Program (CSMIP), (1994), "*Second Quick Report on CSMIP Strong-Motion Data from the San Fernando Valley earthquake of Jan 17, 1994*", *Report OSMS 94-02*, California Strong Motion Instrumentation Program (CSMIP).

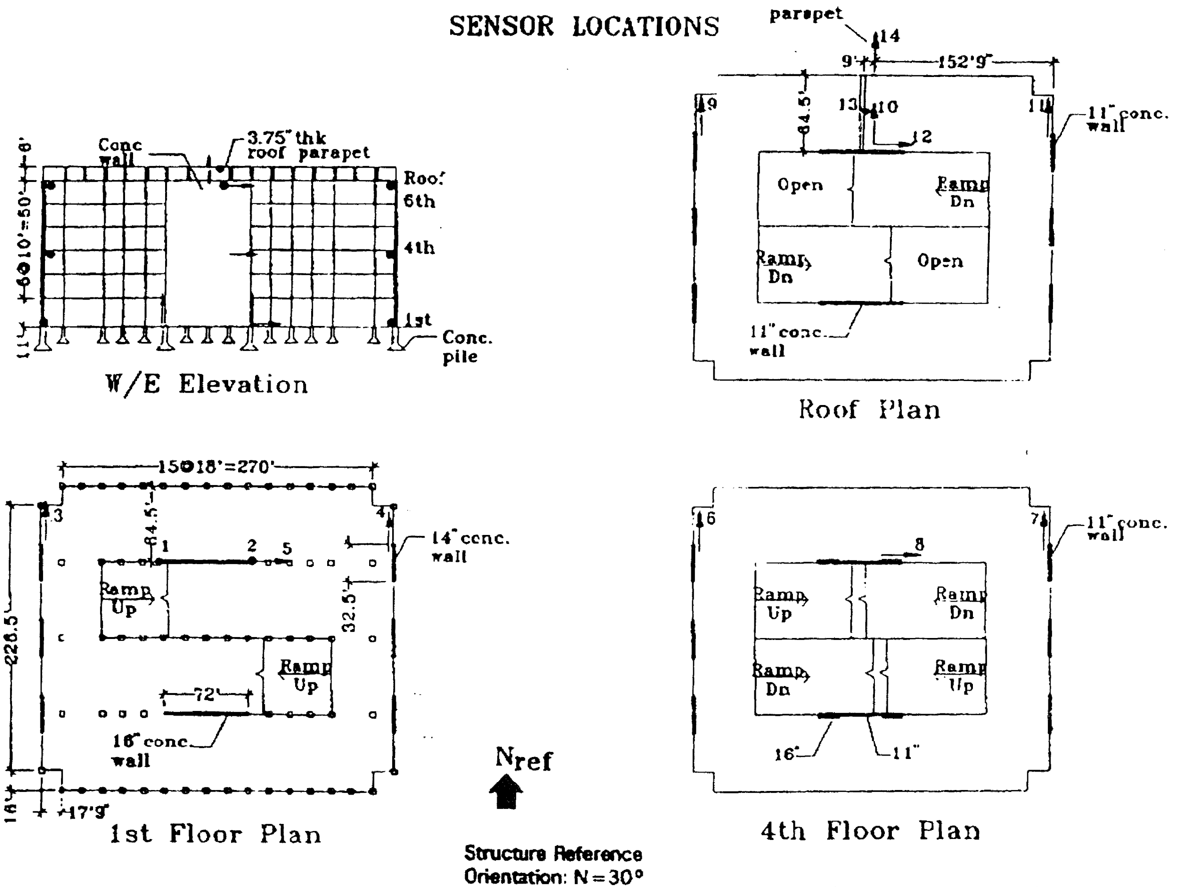
New Civil Engineer, (1994), '*News Analysis - Retrofit rethink*", 27 January, pp 8-11.

Los Angeles - 6-story Parking Structure

(CSMIP Station No. 24655)

Figure 7

SENSOR LOCATIONS



RECORD 24655-C0103-94017

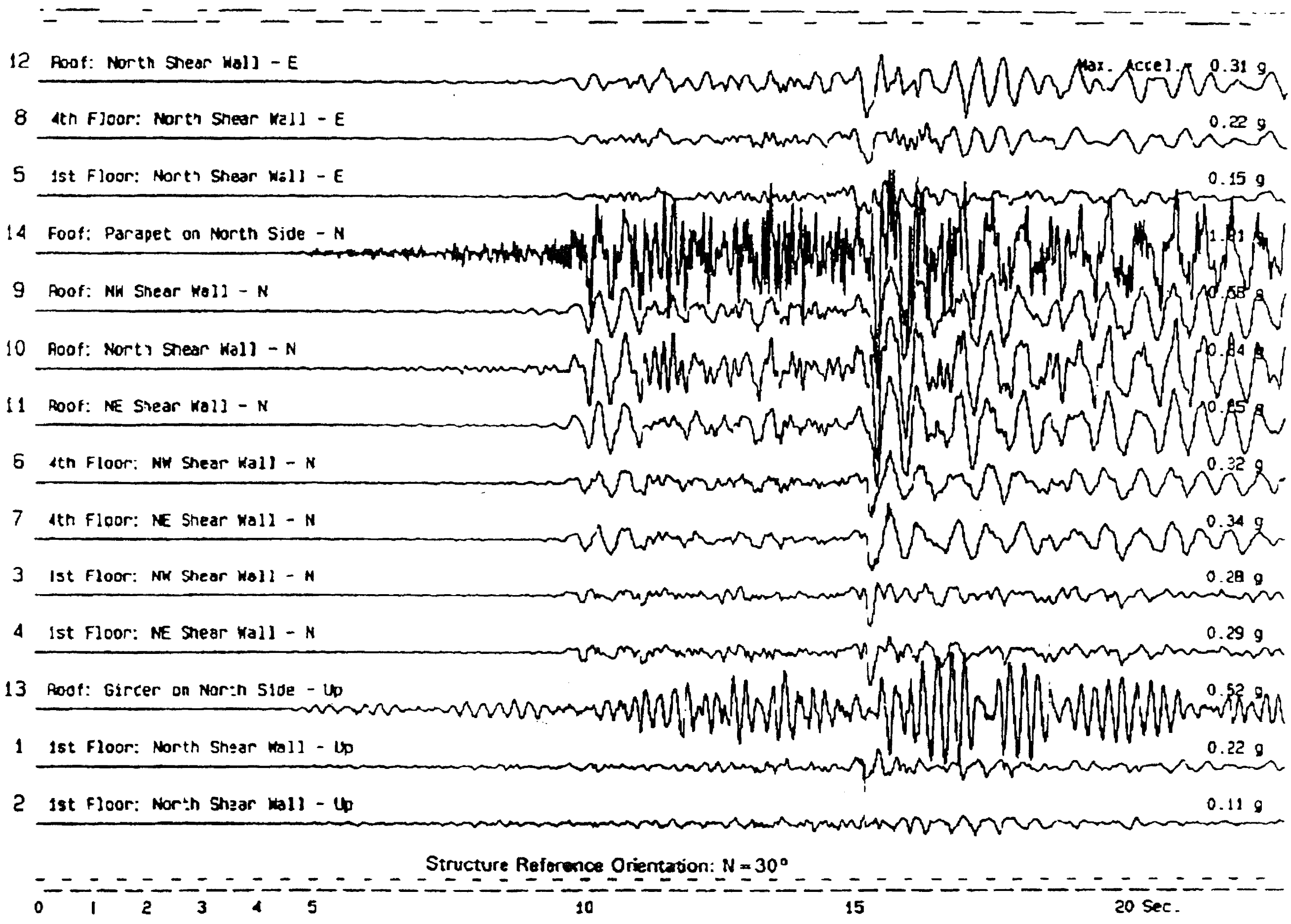


Figure 8

Los Angeles - 7-story University Hospital
(CSMIP Station No. 24605)

SENSOR LOCATIONS

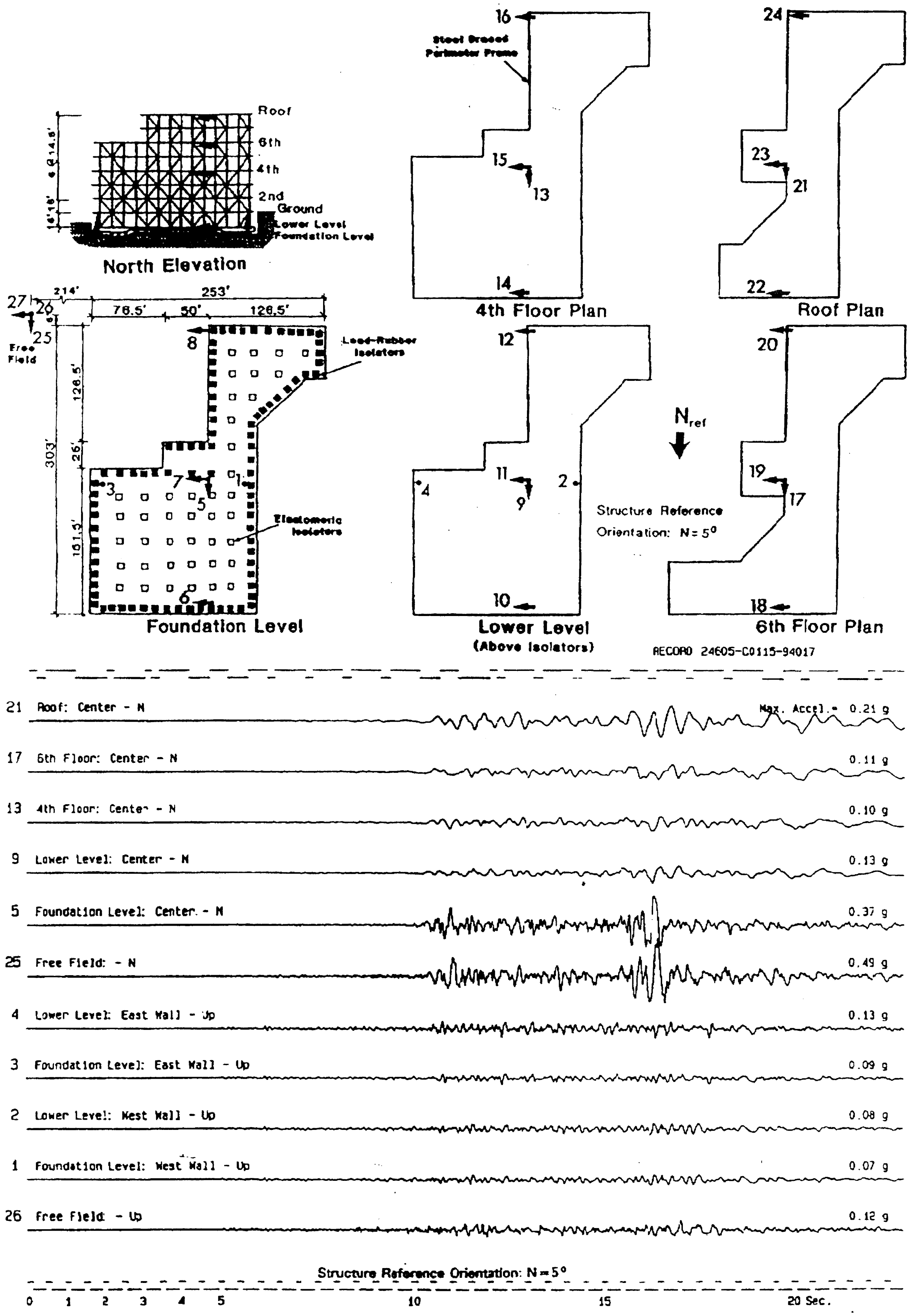


Figure 9

Los Angles - 7-story University Hospital
(CSMIP Station 24605)

RECORD 24605-C0115-94017

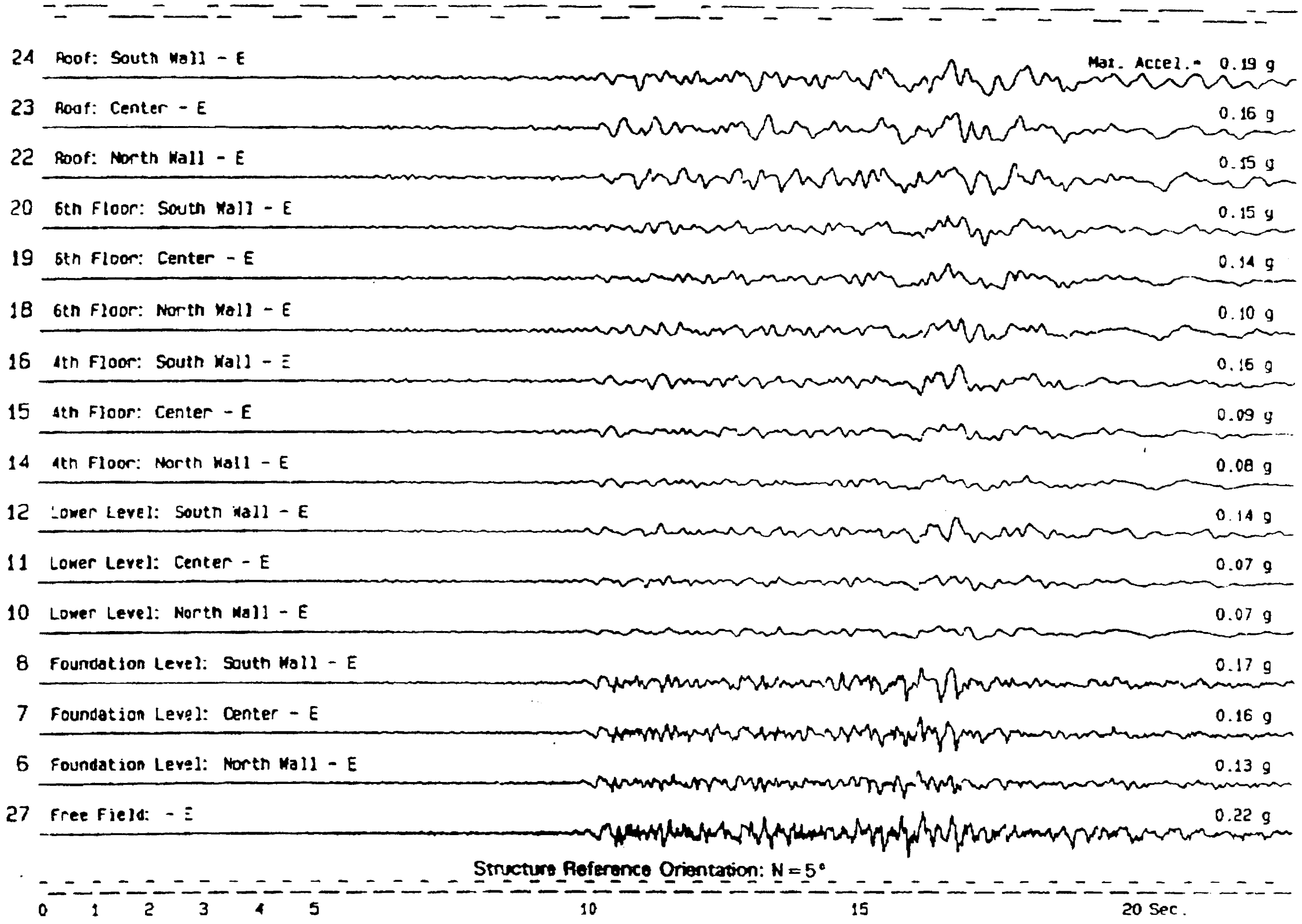


Figure 10

Arleta - Nordhoff Ave Fire Station
(CSMIP Station 24087)

Record 24087-S1584-94017.02

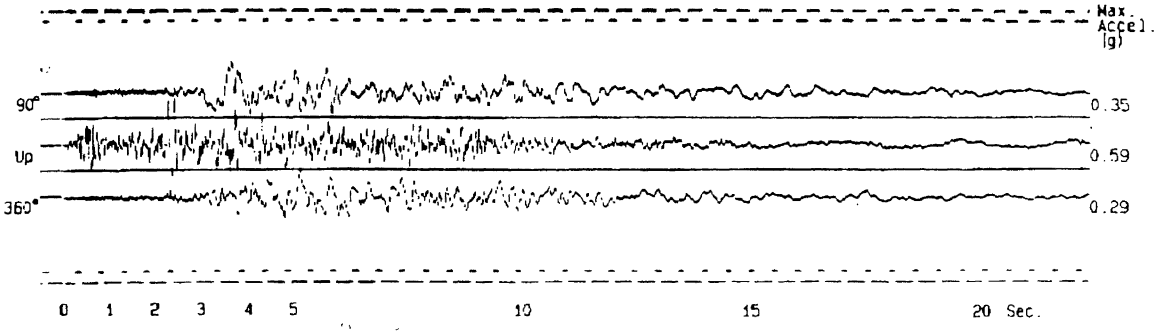
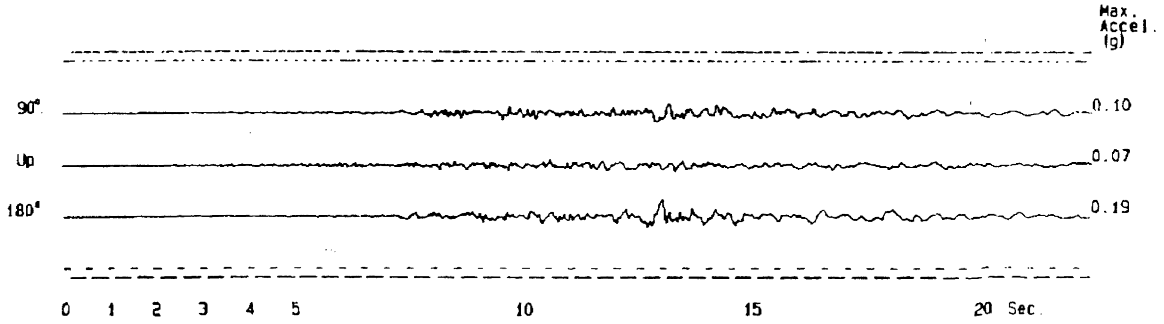


Figure 11

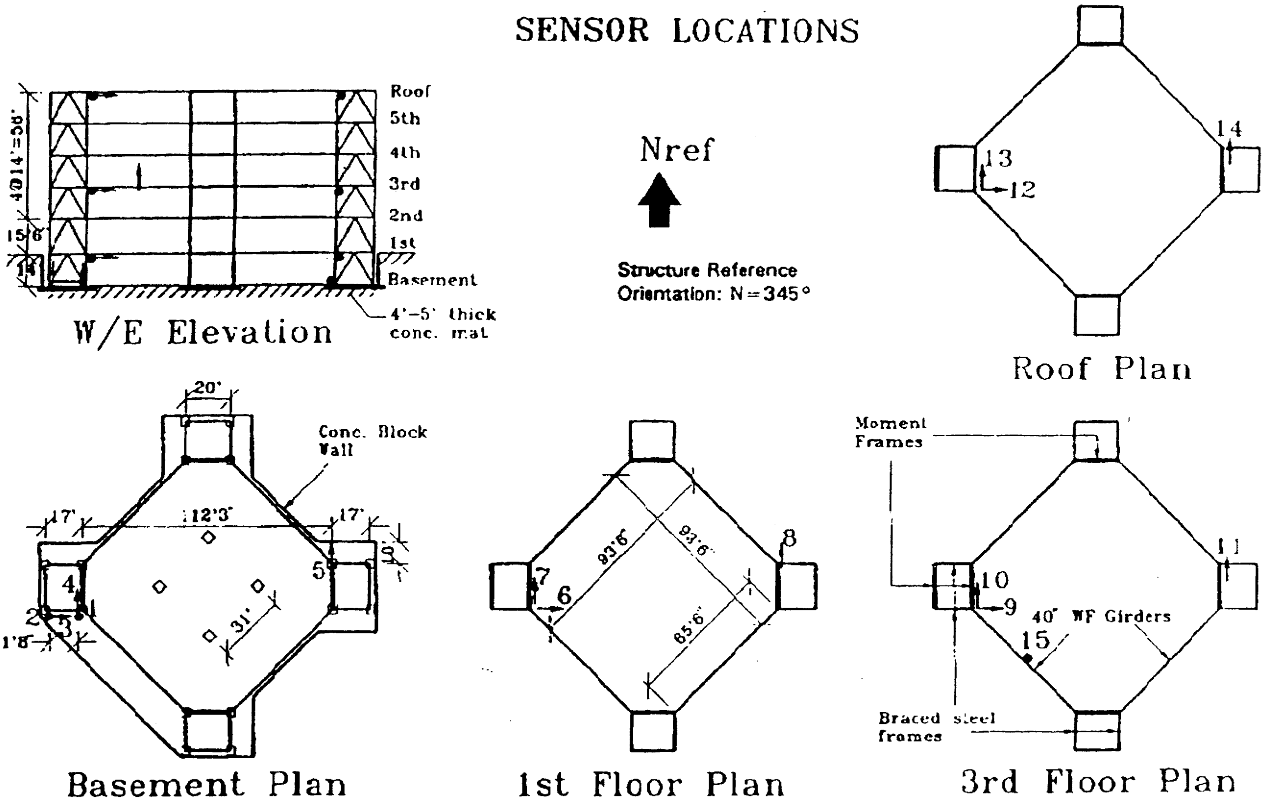
Los Angeles - Pico & Sentous
(CSMIP Station 24612)

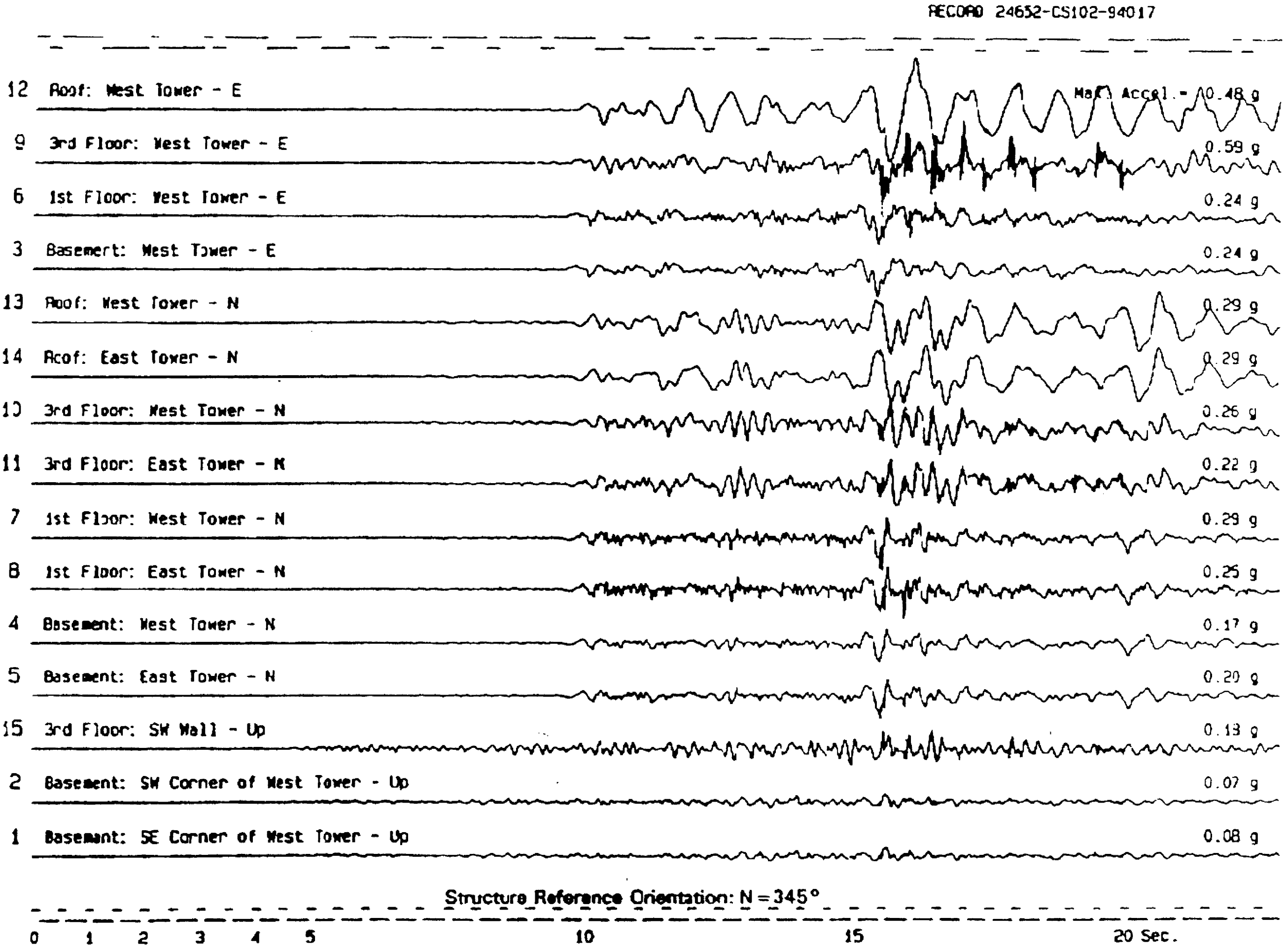
Record 24612-E0276-94018.04



Los Angeles - 6-story Office Bldg.
(CSMIP Station No. 24652)

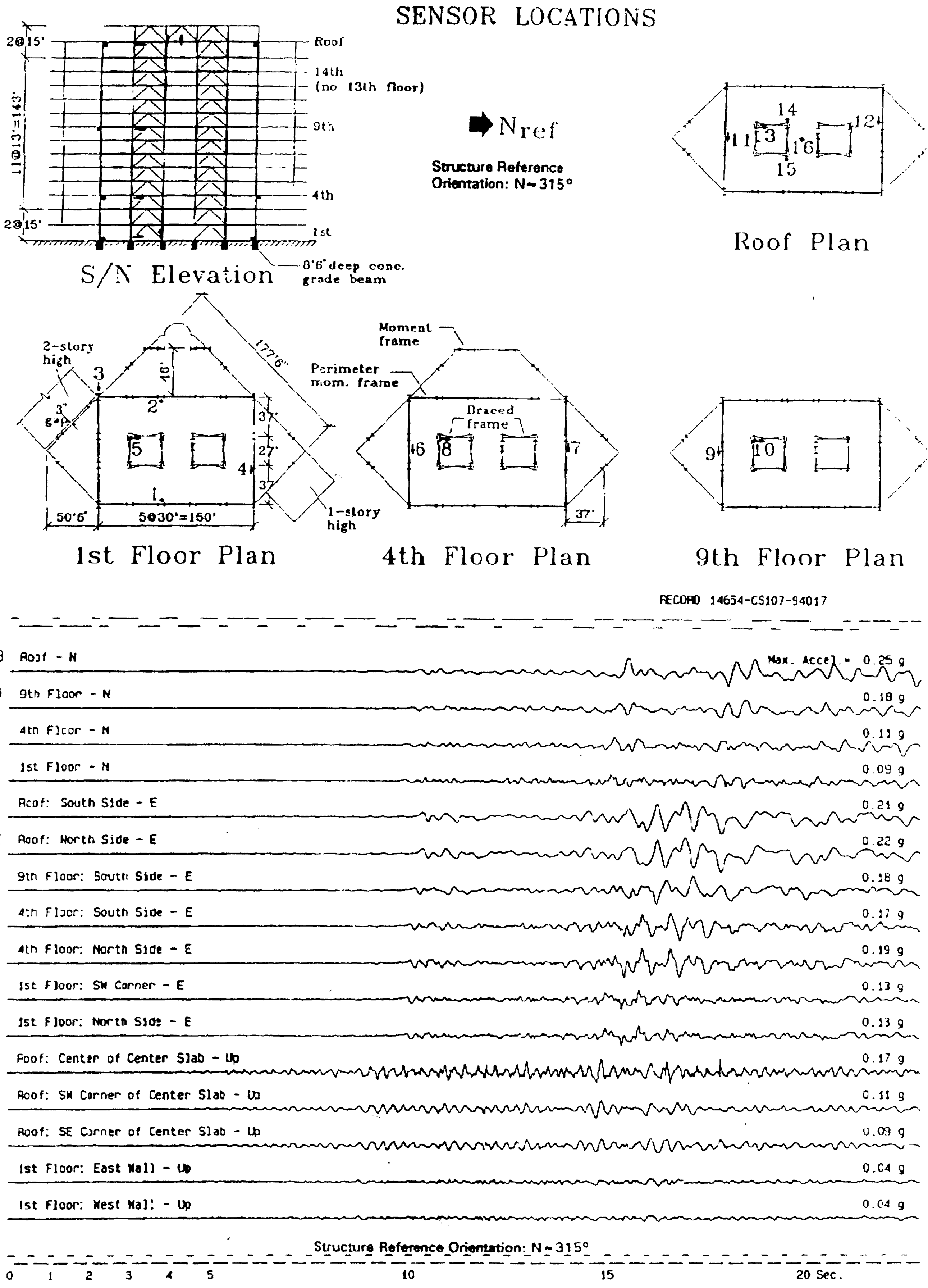
Figure 12





El Segundo - 14-story Office Bldg.
(CSMIP Station No. 14654)

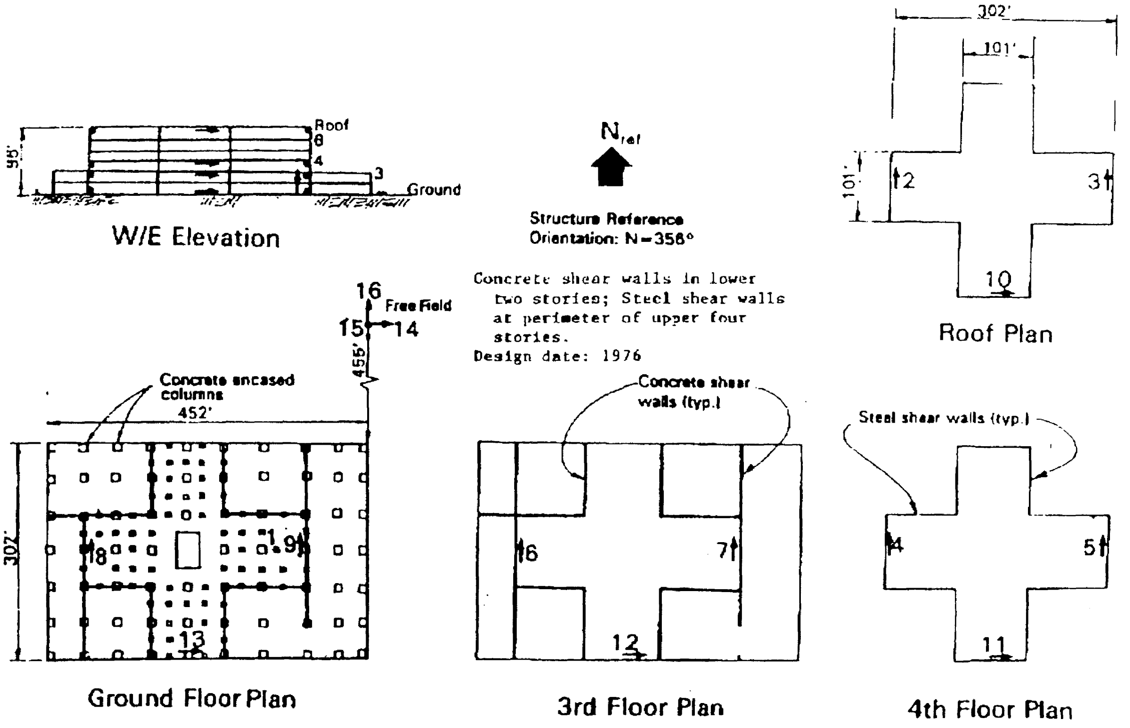
Figure 13

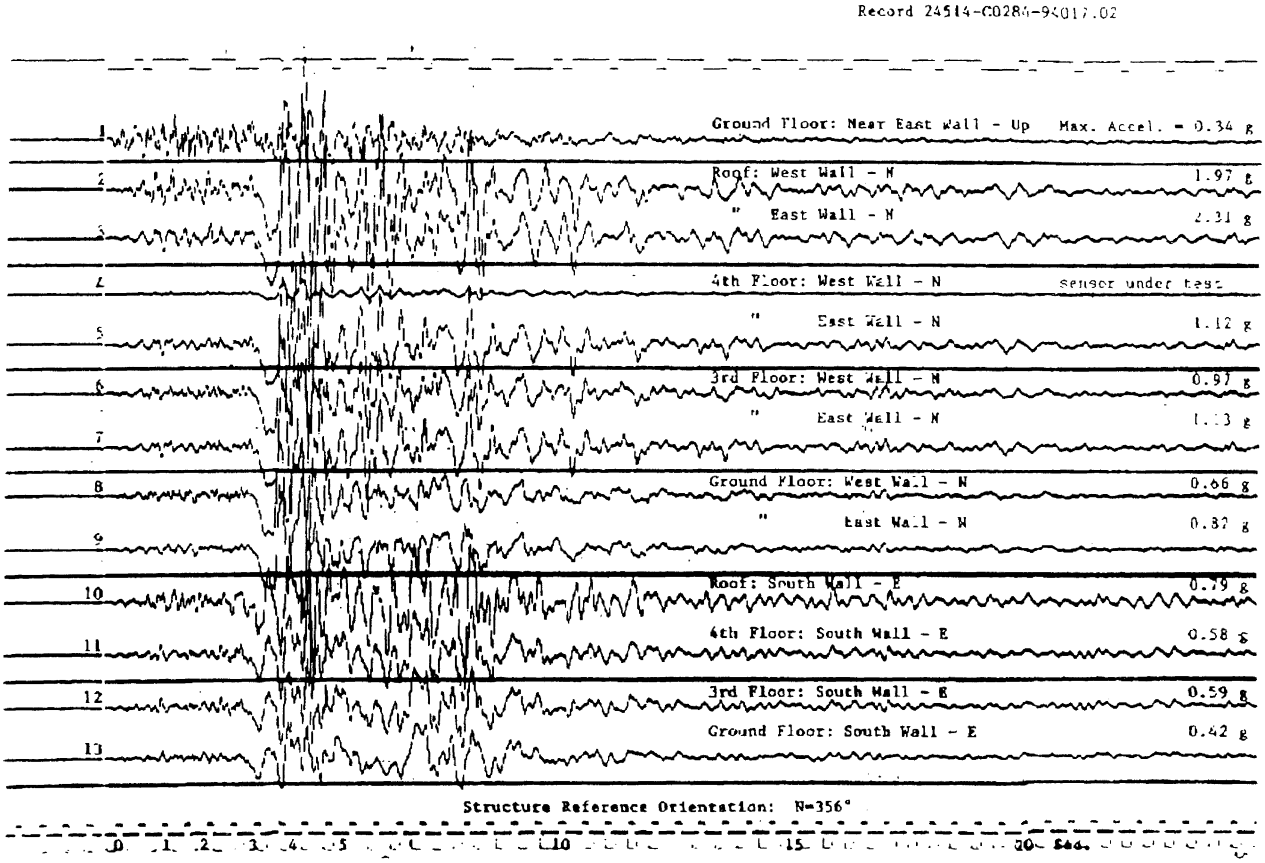


Sylmar - 6-story County Hospital
(CSMIP Station No. 24514)

Figure 14

SENSOR LOCATIONS

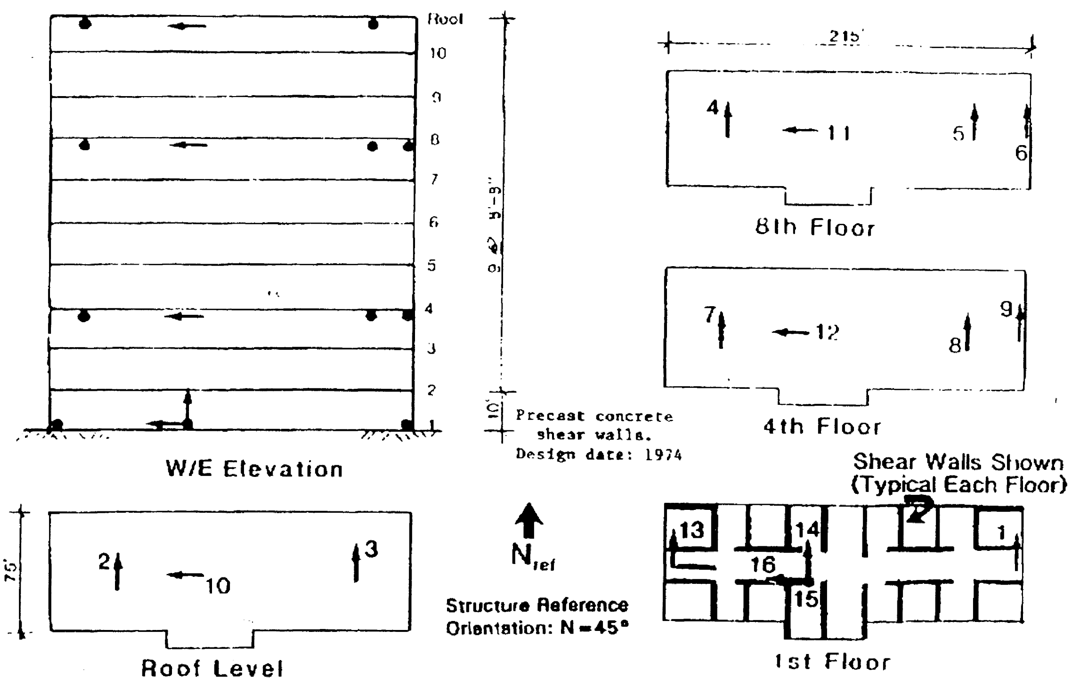


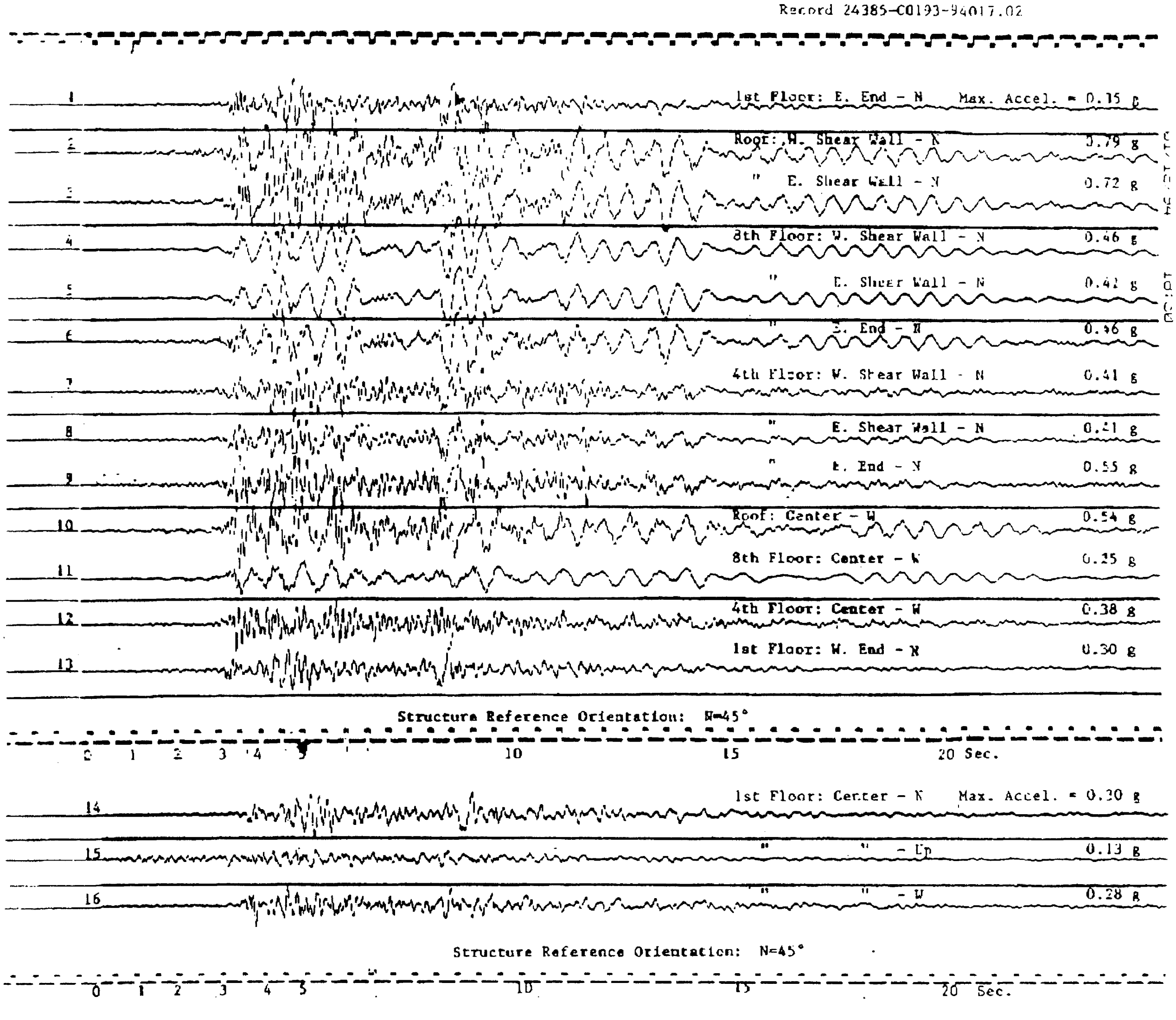


Burbank - 10-story Residential Bldg.
(CSMIP Station No. 24385)

Figure 15

SENSOR LAYOUT

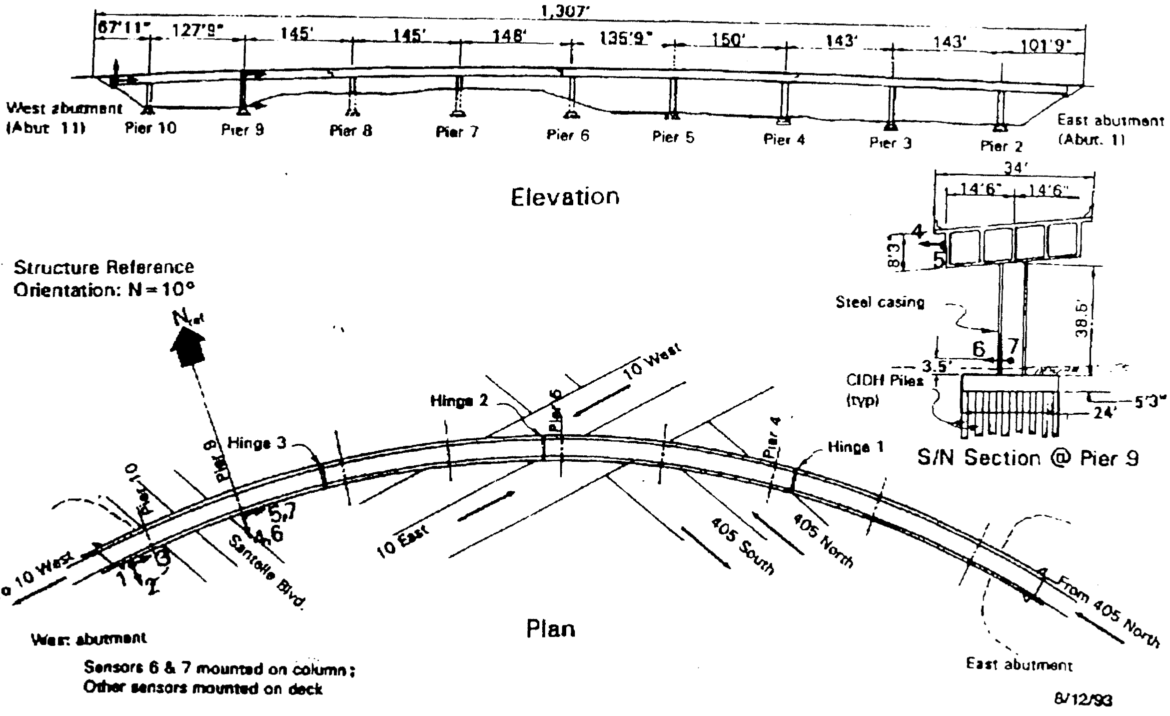


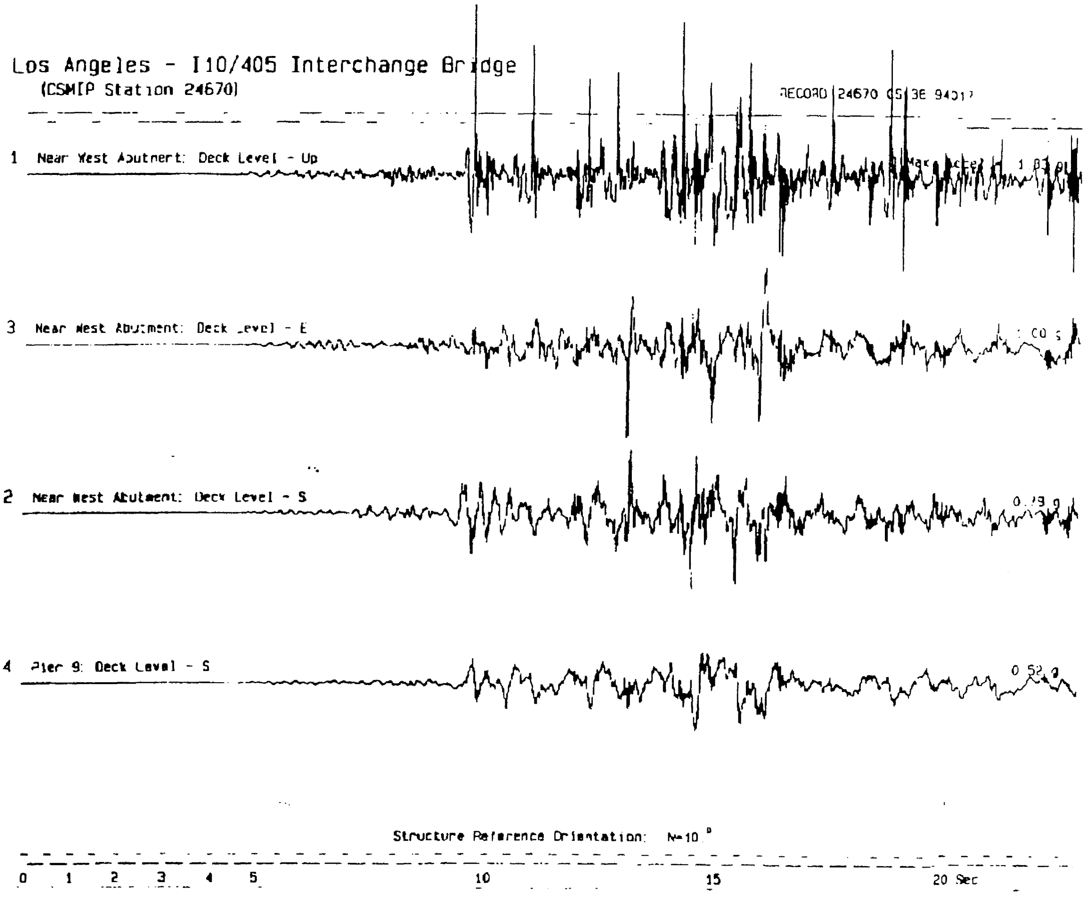


Los Angeles - I10/405 Interchange Bridge
(CSMIP Station No. 24670)

Figure 16

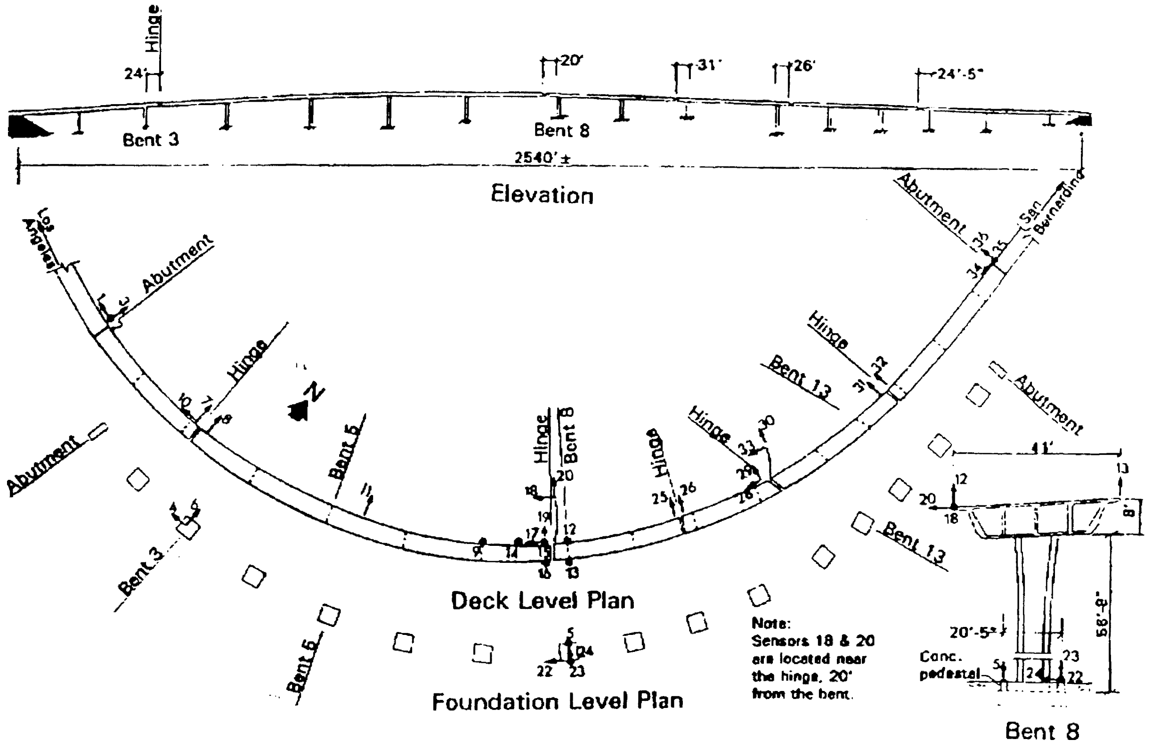
SENSOR LOCATIONS





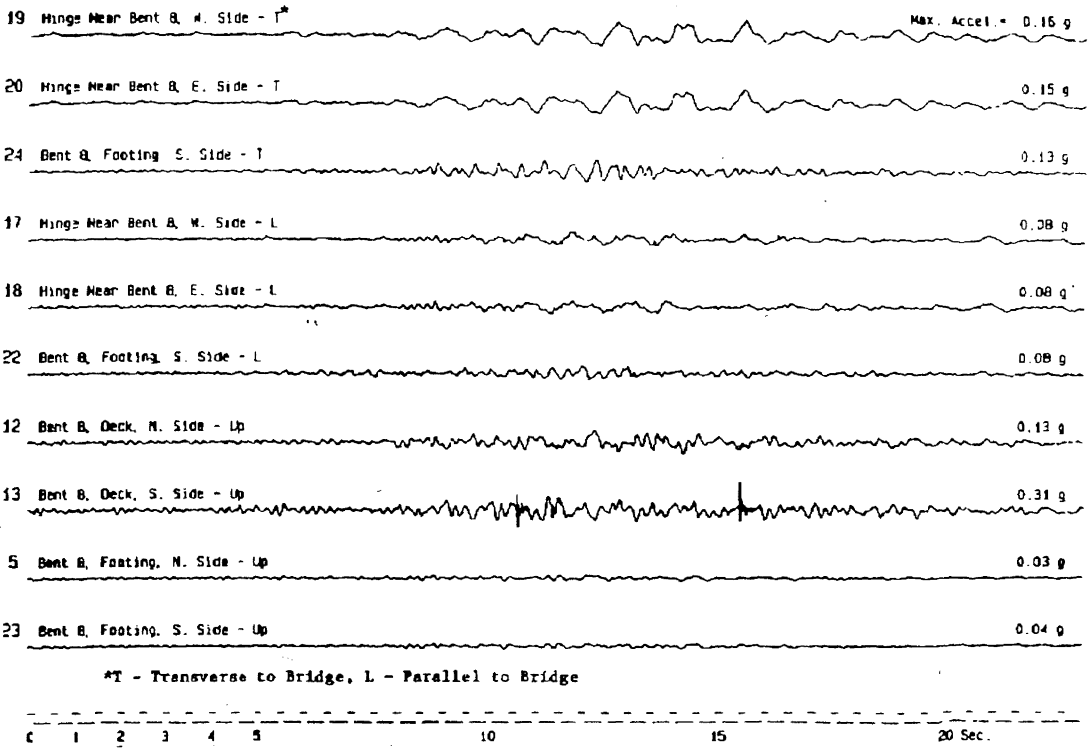
San Bernardino - I10/215 Interchange
(CSMIP Station No. 23631)
SENSOR LOCATIONS

Figure 17



San Bernardino - I10/215 Interchange
(CSMIP Station 23631)

RECORD 23631-CS117-94017

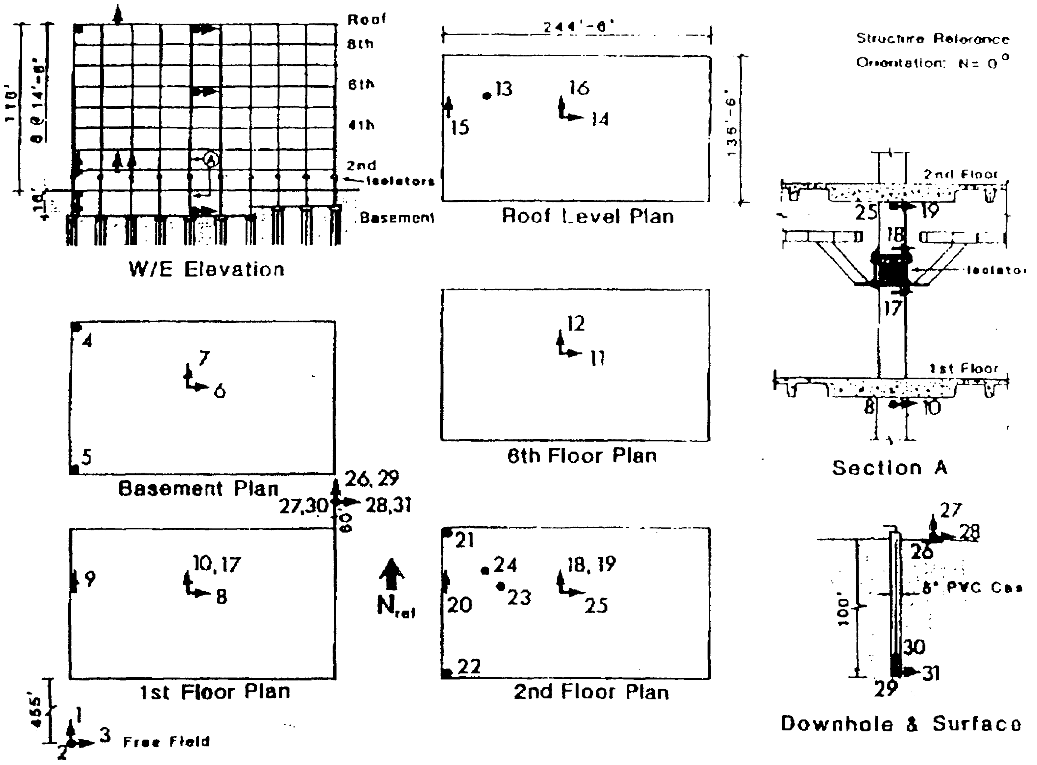


*T - Transverse to Bridge, L - Parallel to Bridge

Seal Beach - 8-story Office Bldg.
(CSMIP Station No. 14578)

Figure 18

SENSOR LOCATIONS



Seal Beach - 3-story Office Bldg.
(CSMIP Station 14578)

RECORD 14578-CS101-94017