U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

# A 98–station Seismic Array to Record Aftershocks of the 1994 Northridge, California, Earthquake

By

S. Gao[1], H. Liu[1], P. M. Davis[1], L. Knopoff[2], and G. Fuis[3]

Open File Report 96-690



[1]Department of Earth and Space Sciences, University of California, Los Angeles, CA 90095; http://www.ess.ucla.edu/~sgao/sgao.html; Email: sgao@ess.ucla.edu

[2]Department of Physics and Institute of Geophysics and Planetary Physics, University of California, Los Angeles, CA 90095

[3]U.S. Geological Survey, Menlo Park, CA 94025

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# A 98-STATION SEISMIC ARRAY TO RECORD AFTERSHOCKS OF THE 1994 NORTHRIDGE EARTHQUAKE

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## ABSTRACT

This report is intended to document the NEAR (Northridge Earthquake Aftershock Recording) experiment and data set so that it can be used by others in the seismological community. During March 26 to April 16, 1994 an array of 98 digital (Reftek) seismic stations recorded over 1,000 Northridge aftershocks. Fifty-three aftershocks were recorded by 40 or more stations. The stations were located in two clusters in Sherman Oaks and Santa Monica, respectively, and along two profiles traversing the San Fernando Valley and the NW part of the Los Angeles Basin. A triggering mode with 125 samples per second, 20 s pre-triggering length, and 60 s post-triggering length was used. The data set has been sorted into event files and submitted to both the SCEC (Southern California Earthquake Center) and IRIS (Incorporated Research Institutions for Seismology) data centers. Seventy-five stations were equipped with L28 4.5 Hz sensors, eight with L22 2.0 Hz sensors and fifteen with L4C 1 Hz sensors. All stations were equipped with 3-component seismometers. Among the over 200,000 files recorded by the network, 37,107 files were sorted into 1550 events. The total size of the sorted waveform data is 1.3

Gigabytes. The data is in SEGY format, which can be easily converted into SAC, AH, SEED, and SIERRA format using codes provided by the IRIS data center.

# INTRODUCTION

During the January 17, 1994 $M_W$=6.7, depth=19 km Northridge earthquake (USGS and SCEC, 1994), Sherman Oaks and mid-Santa Monica experienced much greater damage than neighboring regions at similar distances from the epicenter. This is illustrated in Figure 1 which shows that the distribution of red-tagged buildings (Marshall and Stein, 1994) has higher concentrations in these areas than in the immediate surroundings. The boundary between the heavily damaged and the slightly damaged zones is relatively sharp; the transition takes place over a distance of less than one kilometer. There is no systematic difference in building types, building codes, or earthquake resistance between the heavily and slightly damaged zones. To understand the cause of the concentrated damage, we installed an array of seismic stations to record aftershocks in the two heavily damaged areas as well as along two profiles across the San Fernando valley and the northwestern part of the Los Angeles basin. The data set has been used to study localized amplification factors [Gao et al., 1996] using a Bayesian inversion approach [Jackson and Matsu'ura, 1985], and to test the validity of the use of coda wave amplification factors as an indication of S-wave amplification factors [Liu et al., 1996], as suggested by Kato et al. [1995]. Other work such as finite difference waveform modeling [e.g. Helmberger and Vidale, 1988; Vidale and Helmberger, 1988], and small array analysis [e.g. Frankel et al., 1991] are currently being conducted.

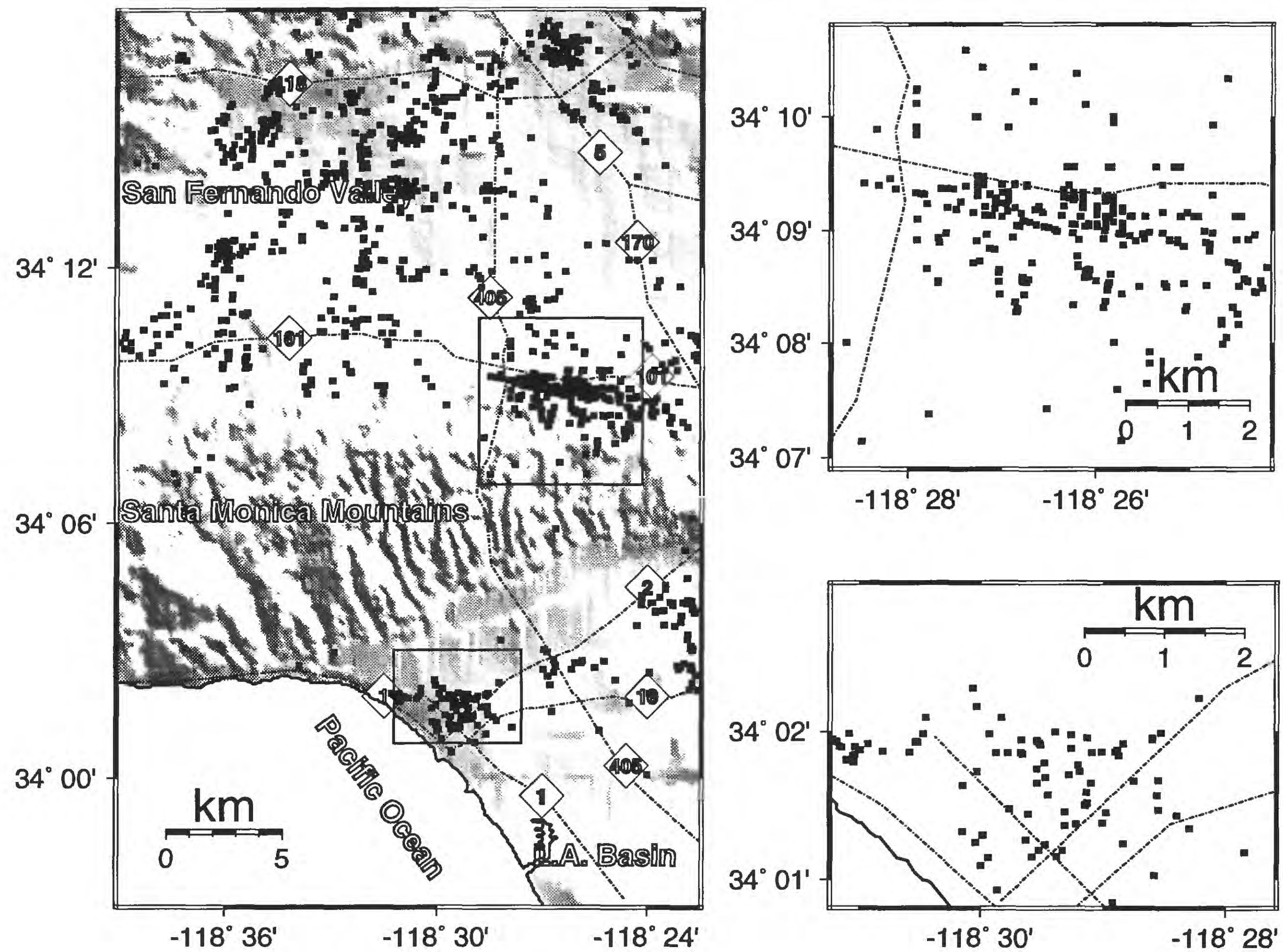


**Figure 1.** Distribution of red-tagged buildings and topography. The coordinates of the red-tagged buildings are from Marshall and Stein (1994). Diagrams on the right are enlargements of the inset areas.

# THE EXPERIMENT

*Background of the experiment*

In the middle of March, 1994, a set of PASSCAL ( Program for Array Seismic Studies of the Continental Lithosphere) instruments arrived at UCLA, originally intended for use by USGS and SCEC to record seismic waves from shots detonated by the Navy in Santa Monica bay. The experiment was postponed until October, 1994 because of environmental concerns. We took advantage of the availability of the instruments to study differential damage caused by the Northridge earthquake. A plan for deployment was made quickly. An announcement was published in the *Daily Bruin*, UCLA's student newspaper, that asked volunteers to allow installation of a seismometer in their backyards. Responses were so abundant that some applicants had to be turned down. Because it was term exam time and most of the field team members were students, almost all of the deployment and disk changing jobs were done during weekends. The project was named the Northridge Earthquake Aftershock Recording (NEAR). The acronym was appropriate since this experiment is *near* UCLA, in contrast with others that we have been working on, such as those in Baikal-Mongolia, East Africa, and on Mars, which are *far* from UCLA. Limited funding was provided for the field work. The hard work of the volunteers was greatly appreciated.

*Field setup*

The 98 stations were located in two clusters and along two profiles (Figure 2 and Table 1). The distance between stations in the two clusters is about 1 km and for the profile stations is about 2 km. The western profile had twenty stations, and the eastern one, sixteen stations. Both profiles were about 35 km long, along lines with strike 165°, and traversed the San Fernando valley, Santa Monica Mountains, and the northwestern part of the Los Angeles Basin. The northern cluster of 36 stations was centered in Sherman Oaks in a 7 km by 7 km area; the distance and azimuth of the center of the Sherman Oaks cluster (station B16) from the epicenter are about 11 km, 133°, respectively. The southern cluster of 29 stations was centered in Santa Monica in a 4 km by 3 km area; the distance and azimuth of this cluster (station F10) from the epicenter are about 21 km, 168°, respectively (Figure 2).

A trigger-mode was used to record relatively strong events. The length of each seismogram was 80 s, which includes 20 s of pre-trigger time. The long pre-trigger time proved to be useful because the S-waves from some events were the triggering signals at some stations, and the long pre-trigger time saved the first P wave arrival. The sampling rate was set at 125 samples per second. The triggering rate and quality of the data depend on the magnitudes and other parameters of the events, as well as ground noise, which in the cities is directly related to local time. The triggering parameters differed from station to station in order to minimize 'false' triggering, which was mostly caused by passing vehicles.

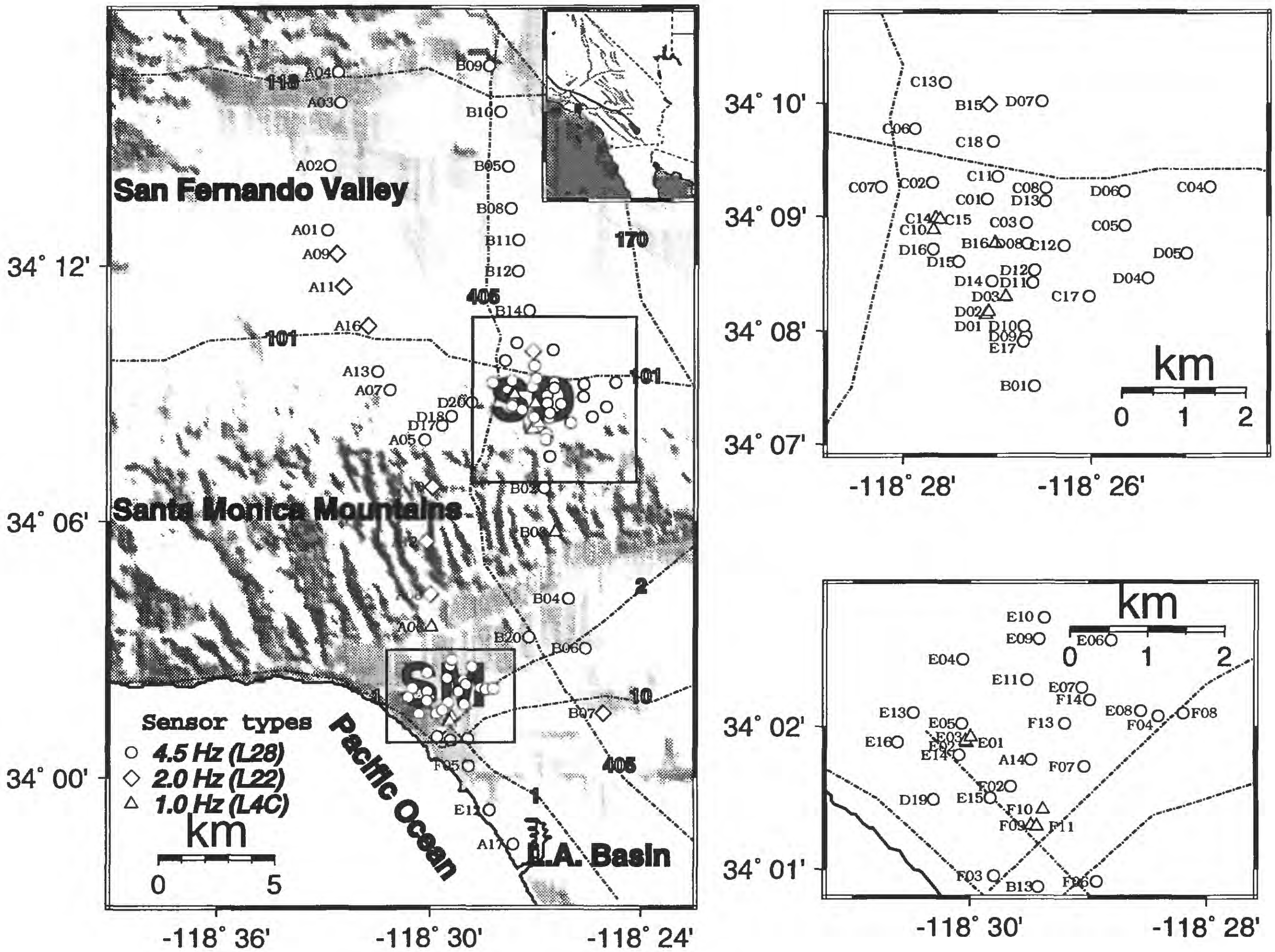


**Figure 2.** Station locations, station numbers, and sensor types. Circles are 4.5 Hz (L28) sensor stations, diamonds are 2.0 Hz (L22) sensor stations, and triangles are 1 Hz (L4C) stations. The inset in the upper right of the main map shows the location in Southern California (small black square). The Sherman Oaks (SO) and Santa Monica (SM) areas are enlarged at the right. Numbered lines are highways; highway 2 is Santa Monica Boulevard.

The Reftek recorder computes the running ratio of the short-time average (STA) and long-time average (LTA) of a selected seismometer component, and an event is declared when the ratio exceeds a programmed threshold, which is called the trigger ratio. Initially, we used the triggering parameters, LTA window = 15 seconds, STA window = 0.2 seconds, Trigger Ratio=8.0 for most of the stations. After the first week, the parameters were adjusted for some of the stations based on their performance. For stations in populated valleys and basins, a lower trigger ratio of 3.0 to 5.0 and shorter STA window of 0.1 to 0.15 s was found to be more effective in discriminating signals in regions of high ground noise. In contrast, for stations on bedrock, a high trigger ratio of 10.0 to 15.0 and small LTA window 5.0 to 10.0 s were effective in reducing vehicle triggers. The number of events recorded by the stations are shown in Table 1.

About half of the stations were equipped with GPS (Global Positioning System) receivers and thus had relatively accurate times and locations (Table 1). The clocks of stations without GPS receivers were corrected every week during station service using external GPS clocks, and the locations for those stations were obtained from USGS 1:24,000 series topographic maps. We note that the GPS signal in the cities is much weaker compared to open areas due to the blockage of buildings. As a result, about 1/4 of the stations with GPS receivers locked on the satellite timing and location signals, on average, less than once a day. As a further result, large uncertainties in the timing and station locations were introduced in some of the data. Clock types and number of locks for stations with GPS receivers are shown in Table 1.

Seventy-five stations were equipped with L28 4.5 Hz sensors, eight with L22 2.0 Hz sensors and fifteen with L4C 1 Hz sensors (Table 1). The amplification, free period, and damping factor are shown in Table 2, obtained by using the average of the calibration test results provided by Aaron Martin at UCSB. Please note that the waveforms submitted to the SCEC and IRIS data centers have not been corrected for instrument response, because we believe it can be done by users easily according to personal preference. Sensor types are listed in Table 1 and shown in Figure 2.

Except for station A17, all of the stations were equipped with either a 72A-06 or 72A-07 Reftek junior DAS (Data Acquisition System). The serial numbers of the DAS for the 06's and 07's start with '6' and '7', respectively. The only station (A17) that used another type of Reftek DAS did not record any useful data. The DAS numbers and DAS locations are shown in Table 3.

Seismograms from one of the best events are shown in Figure 3.

*Participating personnel*

M. Benthien, J. Boyce, J. Davis, M. Davis, P.M. Davis, S. Gao,

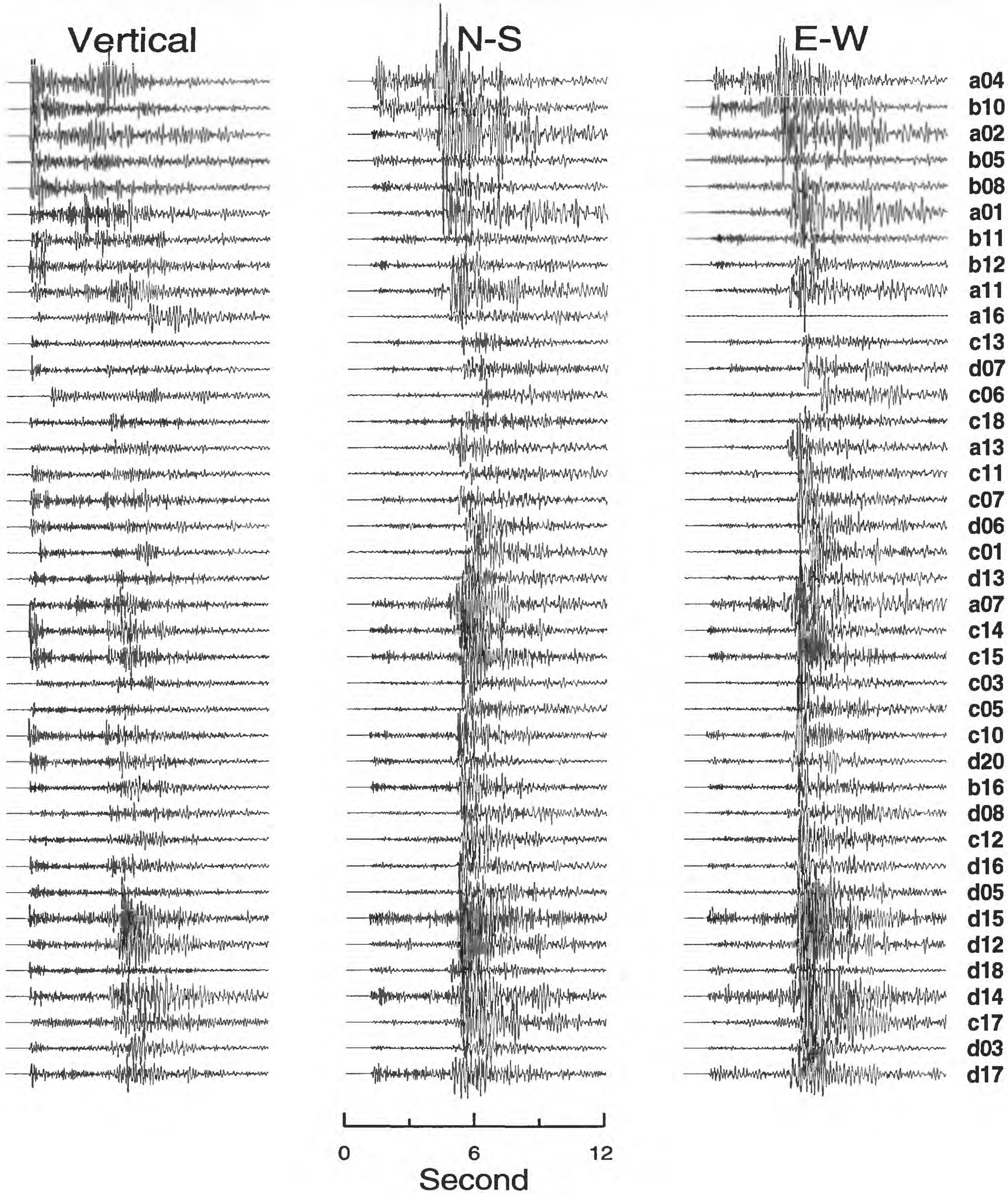


**Figure 3.** Record section from event 093-09-09 showing the vertical, north-south, and east-west components. Only the first 12 seconds after the first arrival are shown. The traces are aligned with the first P-arrivals at 1 sec and are plotted using the same scale.

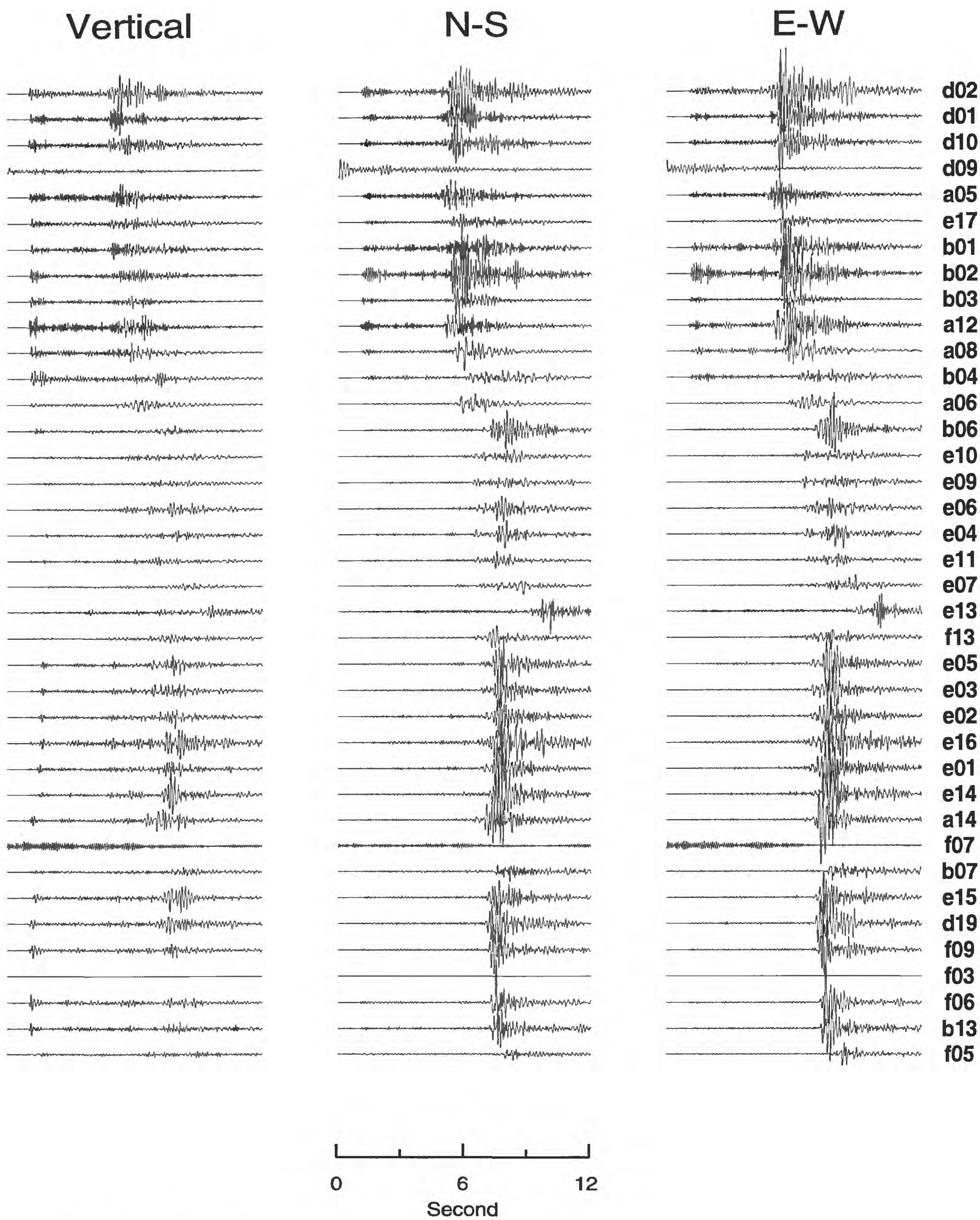


**Figure 3.** (continued)

L. Green, D. Guo, P. Jögi, L. Knopoff, S. Lee, H. Liu, J. Murphy, J. Norris, G. Pei, P. Slack, L. Sung, and M. Winter, were actively participants in the planning, installation, and operation of the stations.

# DATA

## *Data sorting*

In urban areas cultural noise can cause false triggering of the recorders. To make it easier for others to use the data set, we have sorted the approximately 200,000 files into events according to the event catalog provided by the SCEC data center. The theoretical P-wave arrival-time for an event to a given station, $T$, and the trigger time of all the files recorded by the station, $t_i$, where $i$ is the file index, were calculated first. The difference between the two, $\delta t_i = | t_i - T|$, was then calculated and the file with the minimum $\delta t$ was copied into the event directory if $\delta t_i \leq$ 60 s. Apparent timing errors were taken into account in the sorting process. In all 1550 events were recorded by at least one of the stations, and 37,107 files out of the over 200,000 files were sorted into the 1550 events. Therefore about 80% of the files were false triggers. If two events occurred close to each other in time (less than 60 s), the above automatic sorting scheme may put a file in both event directories. In fact, the file may contain waveforms from both events.

*Data format and file names*

Data dumped from the station disks were converted to SEGY format using the REF2SEGY (version 93.285) routine originally written by Early et al. at the PASSCAL Instrument center. The resulting SEGY format data can easily be converted to other formats such as SAC, AH, SEED, and SIERRA by using routines provided by the IRIS data center.

The original files were identified by the hour, minute, and second of the file, the DAS number, and the channel number. The frequent movement of the DAS's (Table 3) made it difficult to identify the station at which a particular file was recorded. Information about DAS and sensor types were not included in the file names. The new file names contain the information about station and channel number, starting hour and minute of the event, and DAS and sensor types. For example, a file named *ssscc yydddhhmmDxSy* indicates that it is an event with origin time at year *yy*, day *ddd*, hour *hh*, and minute *mm*; it was recorded by channel *cc* of station *sss*, where *cc=01* is the vertical component, *cc=02* is the NS component, and *cc=03* is the EW component; the Reftek DAS is *0x*, where *x=6* is for Reftek 72A-06, and *x=7* is for Reftek 72A-07; and the sensor type is *y*, where *y=1* represents L4C, *y=2* represents L22, and *y=3* represents L28.

*Earthquake Information*

Figure 4 indicates that more than 1000 of the 1550 events were

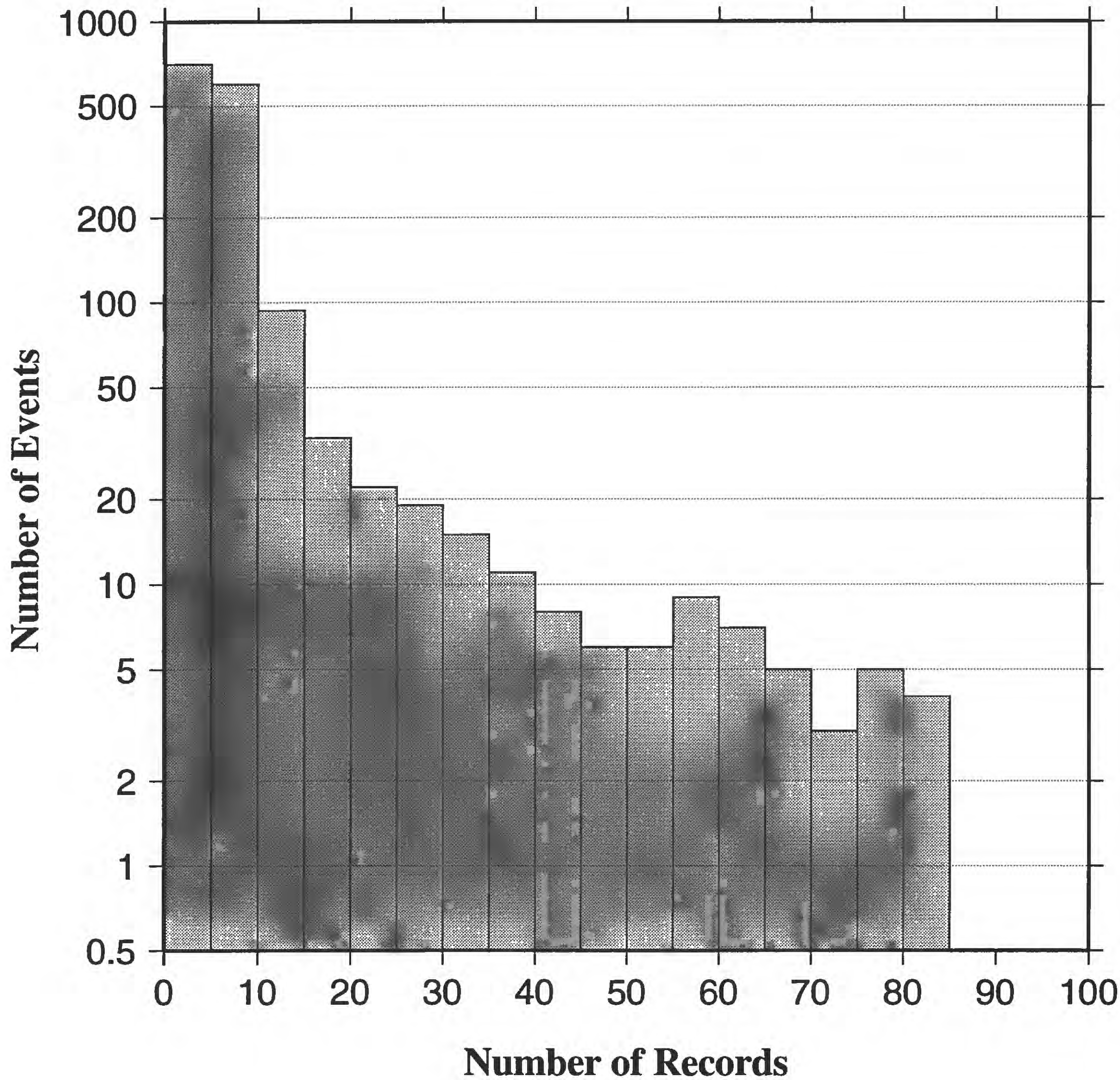


**Figure 4.** Histogram showing the distribution of events as a function of the number of recording stations. The width of bins is 5 stations. Note that a logarithmic scale is used on the Y-axis. More than 1000 events were recorded by less than 10 stations.

recorded by less than 10 stations. Source information on the fifty-three events recorded by at least 40 stations is listed in Table 4, and their locations are shown in Figure 5. Thirty-two of the 53 events were used in a previous report by Gao et al. [1996]. The majority of the events were located in the northern part of the aftershock zone. It must be pointed out that the files were sorted according to the original USGS-Caltech earthquake catalog, while in Gao et al. [1996] a modified catalog provided by Jim Mori at USGS was used. Only strong events are included in the modified catalog. The number of events in the modified catalog is about 1/3 of that in the original catalog. There is almost no difference between the two for data sorting of the strong events.

*Log and error files*

Log and error files provide important information about the data, such as recording parameters, clock state, volts per bit, and timing errors. The log files are named as *sss.ddd.rrrr*.log, and the error files are named as *sss.ddd.rrrr*.err, where *sss* is the station name, *ddd* is the day when the data was dumped from the disk to computer, *rrrr* is the DAS number. The total size of the log and error files is 26 Megabytes.

*Data directory structure*

There are 3 top-level directories in the tape. Under directory Data/, there are 1550 event directories, each contains all the waveform data from the corresponding event; Information about stations and events can be

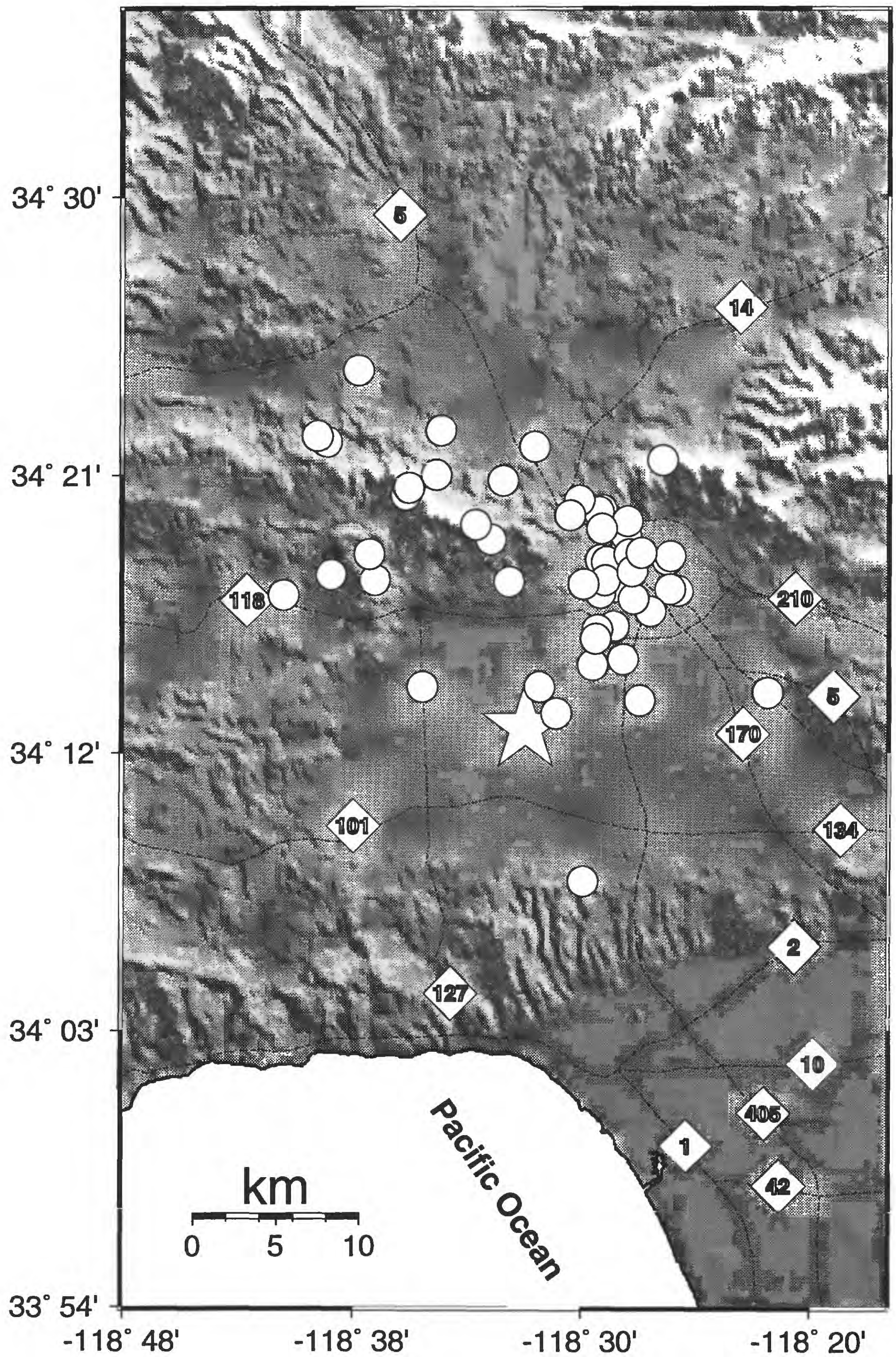


**Figure 5.** Epicenters of the 53 aftershocks which were recorded by at least 40 stations. Diamonds indicate major numbered highways. The epicenter of the main shock is indicated by the star.

found under directory Info/; and Log-files and error-files can be found under directory Logfiles/.

# CONCLUSIONS

An array of 98 stations were installed in the San Fernando Valley, Santa Monica Mountains, and Santa Monica, California area for a 3 week period two months after the 1994 Northridge earthquake to record aftershocks. The data set, together with log and error files and other information such as station and event locations, has been submitted to the SCEC and IRIS data centers and is available for public access.



# ACKNOWLEDGMENTS

We thank the residents of the San Fernando Valley, the Santa Monica Mountains and Santa Monica who kindly gave us permission to install seismic stations on their property. Jim Mori provided help in providing a 9GB disk for preparing the data set, in preparing the report, and in critical reviewing of the manuscript. S. Gao was supported by DARPA under contract F49620-94-1-0161. The field work was supported by the Southern California Earthquake Center under contract to working group D. The Reftek recorders were provided by the PASSCAL instrument center at Stanford University. Support from NSF grant EAR9416213 is also gratefully acknowledged. SCEC publication number 351.

**Table 1.** Station Information

| Station Name | Coordinates | | Sensor Type | No. of Events | Clock Type | No. of GPS Locks |
|---|---|---|---|---|---|---|
| | Latitude | Longitude | | | | |
| A01 | 34.213924 | -118.548698 | L28 | 269 | TRG | 0 |
| A02 | 34.238934 | -118.547394 | L28 | 283 | TRG | 0 |
| A03 | 34.263672 | -118.542450 | L28 | 3 | TRG | 0 |
| A04 | 34.275669 | -118.543457 | L28 | 131 | GPS | 4 |
| A05 | 34.131889 | -118.502686 | L28 | 521 | GPS | 8 |
| A06 | 34.058853 | -118.499374 | L4C | 185 | GPS | 125 |
| A07 | 34.151409 | -118.519020 | L28 | 118 | GPS | 13 |
| A08 | 34.071354 | -118.500000 | L22 | 69 | TRG | 0 |
| A09 | 34.204437 | -118.544273 | L22 | 279 | TRG | 0 |
| A10 | 34.113281 | -118.499084 | L22 | 246 | TRG | 0 |
| A11 | 34.191669 | -118.540886 | L22 | 201 | TRG | 0 |
| A12 | 34.092056 | -118.501823 | L22 | 193 | TRG | 0 |
| A13 | 34.158855 | -118.524872 | L28 | 249 | TRG | 0 |
| A14 | 34.029427 | -118.491402 | L28 | 115 | TRG | 0 |
| A16 | 34.176548 | -118.529167 | L22 | 79 | TRG | 0 |
| A17 | 33.974091 | -118.460670 | L28 | 0 | TRG | 0 |
| B01 | 34.125263 | -118.443398 | L28 | 150 | GPS | 239 |
| B02 | 34.112915 | -118.446220 | L28 | 139 | GPS | 5 |
| B03 | 34.095833 | -118.440758 | L4C | 128 | TRG | 0 |
| B04 | 34.069660 | -118.434639 | L28 | 120 | TRG | 0 |
| B05 | 34.238670 | -118.463280 | L28 | 161 | TRG | 0 |
| B06 | 34.050522 | -118.426300 | L28 | 120 | TRG | 0 |
| B07 | 34.025185 | -118.417915 | L22 | 46 | GPS | 497 |
| B08 | 34.222137 | -118.461845 | L28 | 217 | TRG | 0 |
| B09 | 34.277996 | -118.472137 | L28 | 96 | TRG | 0 |
| B10 | 34.259895 | -118.466927 | L28 | 95 | TRG | 0 |
| B11 | 34.209637 | -118.458328 | L28 | 74 | TRG | 0 |
| B12 | 34.197735 | -118.458328 | L28 | 106 | TRG | 0 |
| B13 | 34.014610 | -118.490417 | L28 | 139 | GPS | 260 |
| B14 | 34.182293 | -118.453384 | L28 | 222 | TRG | 0 |
| B15 | 34.166416 | -118.451508 | L22 | 20 | GPS | 100 |
| B16 | 34.146069 | -118.450325 | L4C | 81 | GPS | 417 |
| B20 | 34.054688 | -118.453125 | L28 | 7 | TRG | 0 |
| C01 | 34.152493 | -118.451706 | L28 | 178 | GPS | 319 |
| C02 | 34.154907 | -118.461411 | L28 | 14 | GPS | 124 |
| C03 | 34.149090 | -118.444923 | L28 | 123 | TRG | 0 |
| C04 | 34.154320 | -118.412445 | L28 | 9 | GPS | 3 |
| C05 | 34.148598 | -118.427498 | L28 | 60 | GPS | 259 |
| C06 | 34.162838 | -118.464607 | L28 | 38 | GPS | 112 |
| C07 | 34.154297 | -118.470573 | L28 | 164 | TRG | 0 |
| C08 | 34.154167 | -118.441406 | L28 | 2 | TRG | 0 |
| C10 | 34.147968 | -118.461243 | L4C | 256 | GPS | 99 |
| C11 | 34.155861 | -118.449867 | L28 | 70 | TRG | 0 |
| C12 | 34.145744 | -118.438126 | L28 | 184 | GPS | 148 |
| C13 | 34.169792 | -118.459114 | L28 | 29 | TRG | 0 |

**Table 1.** (continued)

| Station Name | Coordinates | | Sensor Type | No. of Events | Clock Type | No. of GPS Locks |
|---|---|---|---|---|---|---|
| | Latitude | Longitude | | | | |
| C14 | 34.149746 | -118.460838 | L4C | 117 | GPS | 76 |
| C15 | 34.149471 | -118.460495 | L4C | 120 | GPS | 9 |
| C17 | 34.138355 | -118.433693 | L28 | 167 | GPS | 271 |
| C18 | 34.160938 | -118.450775 | L28 | 43 | TRG | 0 |
| D01 | 34.135647 | -118.451981 | L4C | 174 | GPS | 50 |
| D02 | 34.136059 | -118.451416 | L4C | 161 | GPS | 294 |
| D03 | 34.138283 | -118.448410 | L4C | 81 | GPS | 24 |
| D04 | 34.140984 | -118.423386 | L28 | 311 | GPS | 13 |
| D05 | 34.144588 | -118.416656 | L28 | 102 | GPS | 274 |
| D06 | 34.153667 | -118.427567 | L28 | 104 | GPS | 235 |
| D07 | 34.166927 | -118.442055 | L28 | 237 | TRG | 0 |
| D08 | 34.146019 | -118.444664 | L28 | 144 | TRG | 0 |
| D09 | 34.132534 | -118.444878 | L28 | 314 | GPS | 139 |
| D10 | 34.133999 | -118.445267 | L28 | 185 | GPS | 263 |
| D11 | 34.140366 | -118.443619 | L28 | 179 | TRG | 0 |
| D12 | 34.142200 | -118.443428 | L28 | 255 | GPS | 7 |
| D13 | 34.152264 | -118.441460 | L28 | 61 | GPS | 107 |
| D14 | 34.140572 | -118.450905 | L28 | 70 | GPS | 31 |
| D15 | 34.143444 | -118.456841 | L28 | 157 | GPS | 84 |
| D16 | 34.145138 | -118.461327 | L28 | 66 | GPS | 100 |
| D17 | 34.137371 | -118.494400 | L28 | 307 | TRG | 0 |
| D18 | 34.140820 | -118.489838 | L28 | 269 | TRG | 0 |
| D19 | 34.024738 | -118.505211 | L28 | 95 | TRG | 0 |
| D20 | 34.146542 | -118.480446 | L28 | 51 | GPS | 38 |
| E01 | 34.031418 | -118.500587 | L4C | 153 | GPS | 325 |
| E02 | 34.031605 | -118.500717 | L4C | 74 | GPS | 129 |
| E03 | 34.032093 | -118.499985 | L4C | 110 | GPS | 33 |
| E04 | 34.041210 | -118.501053 | L28 | 124 | GPS | 231 |
| E05 | 34.033703 | -118.501236 | L28 | 135 | GPS | 84 |
| E06 | 34.043381 | -118.480064 | L28 | 44 | GPS | 39 |
| E07 | 34.037910 | -118.484177 | L28 | 43 | GPS | 54 |
| E08 | 34.035156 | -118.475914 | L28 | 119 | TRG | 0 |
| E09 | 34.043594 | -118.490288 | L28 | 9 | GPS | 6 |
| E10 | 34.046093 | -118.489578 | L28 | 227 | TRG | 0 |
| E11 | 34.038803 | -118.492004 | L28 | 81 | TRG | 0 |
| E12 | 33.987370 | -118.471619 | L28 | 69 | TRG | 0 |
| E13 | 34.034897 | -118.508072 | L28 | 198 | TRG | 0 |
| E14 | 34.029949 | -118.501564 | L28 | 171 | TRG | 0 |
| E15 | 34.025002 | -118.497131 | L28 | 76 | TRG | 0 |
| E16 | 34.031467 | -118.510361 | L28 | 49 | GPS | 104 |
| E17 | 34.131767 | -118.445312 | L28 | 101 | TRG | 0 |
| F02 | 34.026291 | -118.494270 | L28 | 93 | GPS | 48 |
| F03 | 34.015884 | -118.496613 | L28 | 45 | TRG | 0 |
| F04 | 34.034504 | -118.473434 | L28 | 35 | TRG | 0 |
| F05 | 34.004688 | -118.481773 | L28 | 60 | TRG | 0 |

**Table 1.** (continued)

| Station Name | Coordinates | | Sensor Type | No. of Events | Clock Type | No. of GPS Locks |
|---|---|---|---|---|---|---|
| | Latitude | Longitude | | | | |
| F06 | 34.015224 | -118.482063 | L28 | 26 | GPS | 57 |
| F07 | 34.028645 | -118.483849 | L28 | 141 | TRG | 0 |
| F08 | 34.034908 | -118.469986 | L28 | 138 | TRG | 0 |
| F09 | 34.021729 | -118.491440 | L4C | 40 | GPS | 18 |
| F10 | 34.023560 | -118.489738 | L4C | 30 | GPS | 114 |
| F11 | 34.021648 | -118.490639 | L4C | 54 | GPS | 26 |
| F13 | 34.033722 | -118.486588 | L28 | 60 | TRG | 0 |
| F14 | 34.036457 | -118.483070 | L28 | 79 | TRG | 0 |

**Table 2.** Instrument constants

| Sensor Name | Free Period | Magnification | Damping |
|---|---|---|---|
| L28 | 0.21 | 27.58 | 0.71 |
| L22 | 0.46 | 84.38 | 0.79 |
| L4C | 0.94 | 180.07 | 0.76 |

**Table 3.** Reftek DAS movement

| Station | Start Time | | | End Time | | | DAS Number |
|---|---|---|---|---|---|---|---|
| Name | Day | Hour | Minute | Day | Hour | Minute | |
| A01 | 084 | 22 | 50 | 120 | 00 | 00 | 7051 |
| A02 | 084 | 23 | 00 | 092 | 19 | 50 | 6095 |
| | 092 | 19 | 51 | 120 | 00 | 00 | 7301 |
| A03 | 084 | 22 | 00 | 120 | 00 | 00 | 7054 |
| A04 | 085 | 00 | 00 | 092 | 20 | 55 | 7057 |
| | 092 | 21 | 00 | 120 | 00 | 00 | 7284 |
| A05 | 087 | 00 | 00 | 093 | 01 | 20 | 6115 |
| | 093 | 01 | 22 | 120 | 00 | 00 | 7285 |
| A06 | 085 | 18 | 00 | 092 | 23 | 35 | 6019 |
| | 092 | 23 | 37 | 120 | 00 | 00 | 7278 |
| A07 | 086 | 19 | 00 | 092 | 17 | 25 | 6018 |
| | 092 | 17 | 27 | 120 | 00 | 00 | 7281 |
| A08 | 085 | 22 | 00 | 092 | 23 | 58 | 7104 |
| | 093 | 00 | 00 | 120 | 00 | 00 | 7293 |
| A09 | 087 | 00 | 00 | 120 | 00 | 00 | 7106 |
| A10 | 086 | 00 | 00 | 120 | 00 | 00 | 7089 |
| A11 | 087 | 19 | 00 | 120 | 00 | 00 | 7093 |
| A12 | 089 | 00 | 00 | 120 | 00 | 00 | 7087 |
| A13 | 086 | 21 | 00 | 120 | 00 | 00 | 7050 |
| A14 | 087 | 19 | 00 | 120 | 00 | 00 | 7100 |
| A16 | 086 | 21 | 00 | 120 | 00 | 00 | 7098 |
| A17 | 088 | 23 | 00 | 120 | 00 | 00 | 0615 |
| B01 | 085 | 18 | 00 | 120 | 00 | 00 | 7079 |
| B02 | 085 | 18 | 00 | 093 | 01 | 38 | 7075 |
| | 093 | 01 | 58 | 120 | 00 | 00 | 6110 |
| B03 | 085 | 20 | 00 | 120 | 00 | 00 | 7066 |
| B04 | 086 | 01 | 00 | 120 | 00 | 00 | 7062 |
| B05 | 086 | 19 | 00 | 120 | 00 | 00 | 7060 |
| B06 | 089 | 00 | 00 | 120 | 00 | 00 | 7068 |
| B07 | 089 | 01 | 00 | 120 | 00 | 00 | 7081 |
| B08 | 086 | 20 | 00 | 120 | 00 | 00 | 7083 |
| B09 | 086 | 17 | 30 | 120 | 00 | 00 | 7044 |
| B10 | 086 | 18 | 00 | 120 | 00 | 00 | 7103 |
| B11 | 086 | 14 | 00 | 120 | 00 | 00 | 7109 |
| B12 | 086 | 22 | 00 | 120 | 00 | 00 | 7113 |
| B13 | 087 | 21 | 00 | 092 | 23 | 50 | 6128 |
| | 093 | 00 | 00 | 120 | 00 | 00 | 7294 |
| B14 | 086 | 23 | 00 | 120 | 00 | 00 | 7046 |
| B15 | 087 | 00 | 00 | 092 | 23 | 58 | 6069 |
| | 093 | 00 | 00 | 120 | 00 | 00 | 7292 |
| B16 | 087 | 01 | 00 | 093 | 00 | 33 | 6064 |
| | 093 | 00 | 38 | 120 | 00 | 00 | 7299 |
| B20 | 085 | 00 | 00 | 120 | 00 | 00 | 7047 |
| C01 | 085 | 18 | 00 | 120 | 00 | 00 | 6099 |
| C02 | 085 | 22 | 00 | 120 | 00 | 00 | 6041 |

**Table 3.** (continued)

| Station Name | Start Time | | | End Time | | | DAS Number |
|---|---|---|---|---|---|---|---|
| | Day | Hour | Minute | Day | Hour | Minute | |
| C03 | 085 | 20 | 00 | 120 | 00 | 00 | 6040 |
| C04 | 085 | 23 | 00 | 120 | 00 | 00 | 6129 |
| C05 | 085 | 19 | 00 | 092 | 17 | 47 | 6131 |
| | 092 | 17 | 53 | 120 | 00 | 00 | 7287 |
| C06 | 085 | 20 | 00 | 099 | 00 | 40 | 6028 |
| | 099 | 00 | 42 | 120 | 00 | 00 | 7104 |
| C07 | 085 | 17 | 00 | 120 | 00 | 00 | 7111 |
| C08 | 085 | 15 | 00 | 120 | 00 | 00 | 7038 |
| C10 | 086 | 18 | 00 | 092 | 21 | 35 | 6051 |
| | 092 | 22 | 15 | 120 | 00 | 00 | 7277 |
| C11 | 087 | 20 | 00 | 099 | 01 | 09 | 6052 |
| | 099 | 01 | 10 | 120 | 00 | 00 | 7075 |
| C12 | 087 | 20 | 00 | 099 | 01 | 42 | 6056 |
| | 099 | 01 | 45 | 120 | 00 | 00 | 7090 |
| C13 | 086 | 17 | 30 | 093 | 16 | 52 | 6083 |
| | 093 | 16 | 53 | 120 | 00 | 00 | 7042 |
| C14 | 086 | 18 | 00 | 120 | 00 | 00 | 7112 |
| C15 | 086 | 22 | 00 | 092 | 22 | 35 | 7042 |
| | 092 | 22 | 39 | 120 | 00 | 00 | 7295 |
| C17 | 087 | 23 | 00 | 120 | 00 | 00 | 6048 |
| C18 | 087 | 18 | 00 | 120 | 00 | 00 | 6116 |
| D01 | 085 | 17 | 00 | 092 | 20 | 21 | 6045 |
| | 092 | 20 | 25 | 120 | 00 | 00 | 7306 |
| D02 | 085 | 21 | 00 | 092 | 20 | 05 | 6132 |
| | 092 | 20 | 08 | 120 | 00 | 00 | 7305 |
| D03 | 085 | 22 | 00 | 092 | 19 | 35 | 6035 |
| | 092 | 19 | 40 | 120 | 00 | 00 | 7286 |
| D04 | 086 | 01 | 00 | 098 | 23 | 42 | 6039 |
| | 098 | 23 | 55 | 120 | 00 | 00 | 7298 |
| D05 | 085 | 00 | 00 | 120 | 00 | 00 | 6134 |
| D06 | 086 | 00 | 00 | 120 | 00 | 00 | 6027 |
| D07 | 085 | 16 | 00 | 120 | 00 | 00 | 7039 |
| D08 | 085 | 18 | 00 | 120 | 00 | 00 | 7041 |
| D09 | 086 | 16 | 00 | 120 | 00 | 00 | 7077 |
| D10 | 086 | 18 | 00 | 120 | 00 | 00 | 7069 |
| D11 | 086 | 18 | 00 | 092 | 21 | 55 | 7045 |
| | 092 | 22 | 00 | 120 | 00 | 00 | 7307 |
| D12 | 086 | 19 | 00 | 092 | 21 | 35 | 7090 |
| | 092 | 21 | 40 | 120 | 00 | 00 | 7304 |
| D13 | 086 | 19 | 00 | 120 | 00 | 00 | 6063 |
| D14 | 086 | 21 | 00 | 092 | 23 | 16 | 6084 |
| | 092 | 23 | 17 | 120 | 00 | 00 | 6100 |
| D15 | 086 | 22 | 00 | 120 | 00 | 00 | 6043 |
| D16 | 086 | 21 | 00 | 120 | 00 | 00 | 6066 |
| D17 | 089 | 19 | 00 | 120 | 00 | 00 | 7056 |

**Table 3.** (continued)

| Station Name | Start Time | | | End Time | | | DAS Number |
|---|---|---|---|---|---|---|---|
| | Day | Hour | Minute | Day | Hour | Minute | |
| D18 | 089 | 18 | 00 | 120 | 00 | 00 | 7059 |
| D19 | 088 | 22 | 00 | 120 | 00 | 00 | 7063 |
| D20 | 089 | 19 | 00 | 120 | 00 | 00 | 6098 |
| E01 | 086 | 22 | 00 | 092 | 18 | 04 | 6109 |
| | 092 | 18 | 05 | 120 | 00 | 00 | 7300 |
| E02 | 086 | 22 | 00 | 092 | 17 | 47 | 6113 |
| | 092 | 17 | 50 | 120 | 00 | 00 | 7290 |
| E03 | 086 | 01 | 00 | 092 | 18 | 35 | 6046 |
| | 092 | 18 | 36 | 120 | 00 | 00 | 7283 |
| E04 | 085 | 19 | 00 | 092 | 22 | 18 | 6021 |
| | 092 | 22 | 23 | 120 | 00 | 00 | 7297 |
| E05 | 085 | 22 | 00 | 120 | 00 | 00 | 6024 |
| E06 | 085 | 19 | 00 | 120 | 00 | 00 | 6118 |
| E07 | 085 | 23 | 00 | 120 | 00 | 00 | 6122 |
| E08 | 086 | 00 | 00 | 120 | 00 | 00 | 7101 |
| E09 | 086 | 19 | 00 | 120 | 00 | 00 | 7085 |
| E10 | 086 | 18 | 00 | 099 | 20 | 22 | 7088 |
| | 099 | 20 | 24 | 120 | 00 | 00 | 6104 |
| E11 | 086 | 17 | 00 | 120 | 00 | 00 | 7080 |
| E12 | 087 | 19 | 00 | 092 | 20 | 33 | 7067 |
| | 092 | 20 | 34 | 120 | 00 | 00 | 7282 |
| E13 | 087 | 00 | 00 | 120 | 00 | 00 | 7053 |
| E14 | 086 | 16 | 00 | 120 | 00 | 00 | 7064 |
| E15 | 087 | 11 | 00 | 098 | 20 | 20 | 6111 |
| | 098 | 20 | 35 | 120 | 00 | 00 | 7057 |
| E16 | 087 | 10 | 00 | 120 | 00 | 00 | 6121 |
| E17 | 088 | 18 | 00 | 120 | 00 | 00 | 7070 |
| F02 | 088 | 00 | 00 | 120 | 00 | 00 | 6034 |
| F03 | 088 | 00 | 00 | 098 | 20 | 28 | 6026 |
| | 098 | 21 | 00 | 120 | 00 | 00 | 7045 |
| F04 | 085 | 18 | 00 | 120 | 00 | 00 | 7099 |
| F05 | 085 | 19 | 00 | 120 | 00 | 00 | 7091 |
| F06 | 086 | 21 | 00 | 092 | 23 | 06 | 6061 |
| | 092 | 23 | 10 | 120 | 00 | 00 | 7302 |
| F07 | 087 | 00 | 00 | 120 | 00 | 00 | 7092 |
| F08 | 087 | 01 | 00 | 120 | 00 | 00 | 7082 |
| F09 | 087 | 22 | 00 | 093 | 00 | 42 | 6107 |
| | 093 | 00 | 50 | 120 | 00 | 00 | 7291 |
| F10 | 087 | 19 | 00 | 093 | 01 | 38 | 6114 |
| | 093 | 01 | 40 | 120 | 00 | 00 | 7279 |

**Table 3.** (continued)

| Station | Start Time | | | End Time | | | DAS Number |
|---|---|---|---|---|---|---|---|
| Name | Day | Hour | Minute | Day | Hour | Minute | |
| F11 | 087 | 19 | 00 | 093 | 01 | 14 | 6124 |
| | 093 | 01 | 20 | 120 | 00 | 00 | 7289 |
| F13 | 087 | 19 | 00 | 120 | 00 | 00 | 7108 |
| F14 | 087 | 18 | 00 | 120 | 00 | 00 | 6032 |

**Table 4.** Events recorded by 40 or more stations

| Origin Time | | | Coordinates | | Mag. | Depth | No. of |
|---|---|---|---|---|---|---|---|
| Day | Hour | Minute | Lat.(°) | Lon.(°) | | (km) | Stations |
| 088 | 02 | 04 | 34.25 | -118.47 | 2.0 | 10.8 | 48 |
| 088 | 07 | 00 | 34.29 | -118.55 | 1.9 | 6.5 | 42 |
| 088 | 17 | 24 | 34.36 | -118.45 | 2.6 | 8.8 | 48 |
| 089 | 23 | 27 | 34.29 | -118.48 | 2.1 | 10.2 | 44 |
| 090 | 09 | 05 | 34.23 | -118.46 | 1.7 | 12.5 | 56 |
| 090 | 11 | 36 | 34.29 | -118.64 | 2.2 | 13.8 | 73 |
| 090 | 12 | 52 | 34.13 | -118.50 | 1.7 | 9.5 | 41 |
| 090 | 15 | 48 | 34.05 | -118.13 | 2.6 | 12.0 | 40 |
| 090 | 19 | 25 | 34.27 | -118.48 | 2.1 | 9.9 | 55 |
| 090 | 20 | 27 | 34.27 | -118.48 | 2.2 | 9.8 | 61 |
| 091 | 06 | 09 | 34.29 | -118.49 | 2.0 | 10.4 | 52 |
| 091 | 09 | 07 | 34.31 | -118.64 | 2.6 | 8.4 | 77 |
| 092 | 04 | 46 | 34.31 | -118.47 | 2.0 | 7.5 | 49 |
| 092 | 12 | 18 | 34.30 | -118.49 | 2.0 | 9.2 | 59 |
| 092 | 14 | 10 | 34.37 | -118.67 | 3.3 | 10.2 | 79 |
| 093 | 04 | 41 | 34.37 | -118.59 | 2.6 | 5.2 | 49 |
| 093 | 09 | 09 | 34.34 | -118.62 | 2.6 | 12.9 | 83 |
| 093 | 14 | 27 | 34.29 | -118.44 | 1.8 | 5.9 | 50 |
| 093 | 18 | 28 | 34.24 | -118.61 | 2.7 | 17.9 | 79 |
| 094 | 05 | 19 | 34.30 | -118.44 | 2.2 | 7.9 | 67 |
| 094 | 10 | 06 | 34.31 | -118.44 | 2.2 | 7.7 | 84 |
| 094 | 12 | 05 | 34.32 | -118.47 | 1.9 | 7.2 | 53 |
| 095 | 05 | 47 | 34.24 | -118.53 | 2.0 | 13.6 | 67 |
| 095 | 06 | 36 | 34.30 | -118.48 | 1.9 | 9.8 | 45 |
| 095 | 08 | 15 | 34.35 | -118.60 | 2.0 | 4.6 | 42 |
| 096 | 09 | 18 | 34.35 | -118.55 | 2.9 | 4.6 | 82 |
| 096 | 10 | 51 | 34.25 | -118.49 | 2.0 | 10.2 | 75 |
| 096 | 19 | 01 | 34.29 | -118.44 | 1.7 | 11.1 | 67 |
| 097 | 04 | 19 | 34.33 | -118.49 | 3.5 | 5.9 | 82 |
| 097 | 04 | 40 | 34.33 | -118.49 | 2.6 | 5.7 | 54 |
| 097 | 09 | 55 | 34.30 | -118.67 | 2.4 | 7.7 | 77 |
| 098 | 13 | 45 | 34.33 | -118.47 | 2.3 | 8.0 | 60 |
| 098 | 14 | 36 | 34.27 | -118.49 | 2.4 | 9.9 | 63 |
| 098 | 17 | 15 | 34.31 | -118.47 | 2.8 | 8.1 | 59 |
| 099 | 12 | 29 | 34.28 | -118.70 | 2.5 | 12.1 | 74 |
| 099 | 13 | 10 | 34.41 | -118.65 | 2.5 | 13.9 | 56 |
| 099 | 15 | 15 | 34.29 | -118.49 | 2.3 | 9.0 | 61 |
| 099 | 19 | 15 | 34.37 | -118.67 | 2.8 | 10.2 | 65 |
| 099 | 21 | 18 | 34.28 | -118.46 | 2.5 | 10.4 | 71 |
| 100 | 08 | 29 | 34.22 | -118.52 | 1.7 | 18.0 | 57 |
| 100 | 16 | 01 | 34.34 | -118.50 | 2.6 | 7.1 | 62 |
| 101 | 02 | 26 | 34.23 | -118.38 | 1.8 | 4.8 | 40 |
| 101 | 04 | 08 | 34.33 | -118.51 | 2.2 | 6.7 | 41 |
| 101 | 05 | 43 | 34.28 | -118.47 | 1.8 | 10.1 | 62 |
| 101 | 12 | 05 | 34.31 | -118.56 | 1.9 | 10.9 | 45 |

**Table 4.** (continued)

| Origin Time | | | Coordinates | | Mag. | Depth | No. of |
|---|---|---|---|---|---|---|---|
| Day | Hour | Minute | Lat.(°) | Lon.(°) | | (km) | Stations |
| 102 | 08 | 06 | 34.30 | -118.47 | 1.8 | 7.8 | 53 |
| 102 | 11 | 27 | 34.26 | -118.49 | 1.8 | 11.8 | 58 |
| 102 | 15 | 12 | 34.32 | -118.49 | 2.3 | 8.2 | 41 |
| 103 | 01 | 57 | 34.34 | -118.61 | 3.2 | 10.4 | 64 |
| 103 | 05 | 59 | 34.31 | -118.46 | 2.0 | 7.9 | 50 |
| 103 | 11 | 18 | 34.37 | -118.53 | 2.8 | 2.0 | 66 |
| 103 | 15 | 29 | 34.29 | -118.50 | 2.6 | 7.3 | 58 |
| 104 | 06 | 42 | 34.32 | -118.57 | 2.5 | 3.4 | 59 |

# REFERENCES


Frankel, A., S. Hough, P. Friberg, and R. Busby, Observations of Loma Prieta aftershocks from a dense array in Sunnyvale, California, *Bull. Seism. Soc. Am., 81*, 1900-1922, 1991.

Gao, S., H. Liu, P.M. Davis, and L. Knopoff, Localized Amplification of Seismic Waves and Correlation with Damage due to the Northridge Earthquake: Evidence for Focusing in Santa Monica, *Bull. Seism. Soc. Am., 86*, S209-S230, 1996.

Helmberger, D.V., and J.E. Vidale, Modeling strong motions produced by earthquakes with two-dimensional numerical codes, *Bull. Seism. Soc. Am., 78*, 109-121, 1988.

Jackson, D.D., and M. Matsu'ura, A Bayesian approach to nonlinear inversion, *J. Geophys. Res., 90*, 581-591, 1985.

Kato, K., K. Aki, and M. Takemura, Site amplification from coda waves: validation and application to S-wave site response, *Bull. Seism. Soc. Am., 85*, 467-477, 1995.

Liu, H., S. Gao, P.M. Davis, and L. Knopoff, Comparison of seismic approaches for strong ground motion prediction using weak motion data, *(In preparation)*, 1996.

Marshall, G.A., and R.S. Stein, severely damaged blocks or buildings judged unsafe for occupation by FEMA, State OES, and City & County of LA inspectors, *USGS Open-File Rep. 94-442*, July 1994.

USGS (U.S. Geological Survey), and SCEC (Southern California Earthquake Center), The magnitude 6.7 Northridge, California, earthquake of 17 January 1994, *Science, 266*, 389-397, 1994.

Vidale, J.E., and D.V. Helmberger, Elastic finite-difference modeling of the 1971 San Fernando, California earthquake, *Bull. Seism. Soc. Am., 78*, 122-141, 1988.