STRONG MOTION DATA FROM THE LARGE CALIFORNIA EARTHQUAKES OF 1992

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ABSTRACT

From April to July, 1992 six earthquakes occurred in California with magnitude greater than 6. The Cape Mendocino earthquake sequence in northern California includes a magnitude 7.0 mainshock and two aftershocks with magnitudes of 6.2 and 6.3. The Landers sequence in southern California includes the Joshua Tree, Landers and Big Bear earthquakes with magnitudes of 6.1, 7.3 and 6.2, respectively. Strong-motion records were recovered from more than 500 stations of the California Strong Motion Instrumentation Program (CSMIP) following these earthquakes. For example, the Landers earthquake produced an extensive set of strong motion accelerograms at 144 CSMIP stations that recorded the largest earthquake to occur in California since 1952.

We present four results obtained from the CSMIP strong motion data. First, the strong motion records from the Cape Mendocino mainshock have some of the highest accelerations ever recorded. The Cape Mendocino station recorded a peak acceleration near 2 g, the largest acceleration ever recorded in California. Also, one of the highest accelerations ever recorded on a structure, 1.4 g, occurred on the ground near the abutment of a freeway overpass near Rio Dell. Second, the most significant aspect of the records from the Landers earthquake is their long duration, compared to most records that have been obtained in California. For example, the duration of strong shaking was 2-3 times longer than for the magnitude 7 Loma Prieta earthquake of 1989. Third, recordings from both mainshocks have significantly more long period energy in the ground motion than seen in previous strong motion recordings. Fourth, the strong motion records from these earthquakes have larger peak accelerations than most existing attenuation models would predict. Also, the Landers peak accelerations show less attenuation with distance.

THE EARTHQUAKE SEQUENCES

Table I summarizes the earthquake magnitudes (moment (M_w), surface (M_S) and local (Richter) (M_L)) and mechanism as estimated by the U. S. Geological Survey, California Institute of Technology and University of California, Berkeley for the 1992 earthquakes. The moment magnitude scale is used throughout this paper. Important aspects of each sequence and CSMIP strong motion data recovered from these earthquakes are discussed briefly in the text and more extensively in the references given in the bibliography.

Cape Mendocino Sequence: The magnitude 7.0 mainshock was at the time the largest earthquake in California since the 1989 Loma Prieta earthquake. The sequence caused over 350 reported injuries, destroyed over 200 buildings and caused damage to an additional 900 structures mainly in the towns of Petrolia, Ferndale, Rio Dell, Scotia and Fortuna (Oppenheimer and others, 1993). The two magnitude 6 aftershocks occurred northwest of the mainshock and all three earthquakes occurred within 25 km of each other. Because this earthquake sequence occurred near the southern end of the Cascadia subduction zone the records are important for prediction of ground shaking both in California and in the Pacific Northwest. Prior to these earthquakes the Cascadia subduction zone had exhibited little subduction-related seismic activity, and the mainshock recordings are the first strong-motion accelerograms from a large interplate earthquake.

Landers Sequence: The magnitude 6.1 Joshua Tree earthquake occurred on April 22 under the Little San Bernardino Mountains about 17 km east of Desert Hot Springs and 22 km northeast of Palm Springs and caused light to moderate damage near the epicenter. No primary surface faulting was observed. This earthquake has been considered a pre-shock of the Landers earthquake by Sieh and others (1993) because they consider the two earthquakes related in space and time.

The magnitude 7.3 Landers earthquake occurred 30 km north of the Joshua Tree epicenter on June 28. The mainshock is the largest earthquake to occur in the contiguous United States since 1952 and the largest earthquake with an extensive set of strong motion recordings. Extensive right-lateral strike-slip faulting was observed, with maximum horizontal offset of 6 meters, along faults that trend northwestward across the Mojave Desert for over 70 km (Sieh and others, 1993). Most of the damage and injuries were confined to the desert and mountain towns in the epicentral area.

Approximately 3 hours after the Landers earthquake, the magnitude 6.2 Big Bear earthquake occurred about 35 km west of the Landers epicenter. The epicenter is located in the San Bernardino Mountains, about 11 km southeast of Big Bear Lake and 45 km northeast of San Bernardino. No primary surface faulting was observed. Most of the damage due to this earthquake was confined to the mountain communities in the Big Bear area.

Table I

Earthquake Magnitude and Mechanism

Earthquake Name	Date	Depth	M_w	M_S	M_L	Mechanism
Cape Mendocino	4/25/92	11 km	7.0	7.1	7.0	Thrust
Aftershock No. 1	4/26/92	19 km	6.2	6.6	6.4	Strike-slip
Aftershock No. 2	4/26/92	22 km	6.3	6.6	6.4	Strike-slip
Joshua Tree	4/22/92	12 km	6.1	6.3	6.1	Strike-slip
Landers	6/28/92	9 km	7.3	7.6	6.8	Strike-slip
Big Bear	6/28/92	7 km	6.2	6.6	6.5	Strike-slip

STRONG MOTION DATA

Cape Mendocino Sequence Strong Motion Data: Strong-motion records were recovered from 14 CSMIP stations after the Cape Mendocino earthquakes of April 25-26, 1992. These 14 stations include 10 ground-response stations and 4 extensively-instrumented structures. The 4 structures include 2 buildings, a freeway overpass and a dam. The epicentral distance of the stations ranges from 4 km for the closest (Cape Mendocino) to about 110 km for the farthest (Fort Bragg).

The records recovered from the mainshock have some of the highest accelerations ever recorded. Peak accelerations near 2 g were recorded at the Cape Mendocino station, approximately 4 km southwest of the epicenter on hard sandstone. Figure 1 shows the acceleration, velocity and displacement waveforms in the north-south direction. A peak velocity of 126 cm/sec and a peak displacement near 70 cm (on the vertical component) was calculated. The duration of strong shaking was about 7 seconds at this station. Significant long-period energy was recorded at this site as shown by these waveforms. Figure 2 shows the response spectra from the Cape Mendocino record compared to that of the Taft (1952 Kern County earthquake) and El Centro (1940 Imperial Valley earthquake) stations. The Cape Mendocino spectrum is larger than the other spectrum for all periods shown.

Figure 3 shows horizontal peak ground acceleration from the mainshock compared to the Joyner-Boore attenuation relation (Joyner and Boore, 1988). Clearly, the data do not cluster about the median curve, but lie principally above it. For example, only 3 of the 16 values fall below the median peak acceleration curve.

Figure 4 shows the sensor locations for the Highway 101 Rio Dell overpass and the first 20 seconds of the acceleration waveforms for 5 transverse channels. As shown in the figure, this two-span skewed bridge recorded a transverse acceleration of 1.2 g at the deck level on the west end of the bridge. The corresponding peak acceleration at the east end was 0.69 g. Also, one of the highest accelerations ever recorded on a structure, 1.38 g, occurred on the ground near the west abutment. The duration of strong shaking was about 7 seconds at this station. The largest previous acceleration recorded at this bridge was 0.59 g during the 1982 Rio Dell earthquake.

During the two magnitude 6 aftershocks the largest accelerations recorded by ground-response stations were 0.60 and 0.57 g at Petrolia. The largest horizontal acceleration recorded on a structure was 0.91 g on the Rio Dell overpass structure located 42 km from the epicenter of the first aftershock. The acceleration in the free-field of the bridge was 0.55 g. At a 1-story supermarket in Fortuna 0.18 g horizontal acceleration was recorded at the ground floor and 0.87 g at the roof level in the out-of-plane direction at the top of the wall during the first aftershock. These are the largest accelerations ever recorded at this building. Similar large motions of the roof diaphragm have been recorded at other buildings with stiff walls and flexible diaphragms.

<u>Landers Sequence Strong Motion Data:</u> Strong-motion records were recovered from over 100 CSMIP stations after the magnitude 6.1 Joshua Tree earthquake on April 22. At the two closest CSMIP stations (Desert Hot Springs and Joshua Tree) peak accelerations of 0.22 and 0.32 g were recorded at 17 and 20 km from the epicenter. Duration of strong shaking was about 5 seconds at both stations.

Strong-motion records were recovered from a total of 144 CSMIP stations after the Landers earthquake. The epicentral distance of the stations ranges from 14 km for the closest (Joshua Tree) to about 215 km for the farthest (Santa Felicia Dam). At these stations, a total of 224 records were obtained of the motion at over 1000 strong-motion sensors. The 144 stations include 88 ground-response stations and 56 extensively-instrumented structures. The 56 structures include 47 buildings, 6 dams and a major freeway interchange. The instrumented buildings included 4 that have been seismically isolated. These buildings are 2, 5, 8 and 9 stories in height and recorded peak accelerations at the foundation level were between 0.04 and 0.11 g. The acceleration response of these seismically isolated buildings was as high as 0.19 g at the roof (see Huang and others (1993) in this Proceedings).

Figure 5 shows horizontal peak ground acceleration from the mainshock compared to the Joyner-Boore (1988) attenuation relation. The peak acceleration values generally lie at or above the median curve and show less attenuation with distance than predicted by this model, especially at longer distances. Figure 6 shows the response spectra from three stations (Yermo, Joshua Tree and Inglewood) that recorded the Landers mainshock compared to response spectra at Taft (1952 Kern County earthquake) and El Centro (1940 Imperial Valley earthquake). The Landers spectra are generally larger than the other spectra, especially at long periods.

The most significant aspect of the records from the Landers earthquake is their long duration, compared to most records that have been obtained in California. For example, Figure 7 shows records from 4 California earthquakes (Landers, Loma Prieta, Big Bear and Whittier) recorded at similar distances (10 to 20 km). The record from the Landers earthquake has duration of strong shaking of about 30 seconds. This duration is 2 to 4 times longer than the duration of the other three records.

Evidence for the propagation of the Landers earthquake northward from the epicenter may be inferred by comparing the acceleration, velocity and displacement waveforms at two stations, Yermo and Joshua Tree (Figure 8). The station at Yermo, 84 km north of the epicenter has a peak acceleration near 0.24 g. The only other CSMIP station with higher peak acceleration is Joshua Tree (0.28 g) located 14 km southeast of the epicenter. Yermo has the largest peak velocity and displacement measured at CSMIP stations. The peak velocity is 50 cm/sec and the peak displacement is larger than 40 cm (1.3 feet). For comparison, the peak values at Joshua Tree are 43 cm/sec and 16 cm.

A peak acceleration of 0.88 g was recorded during the Landers earthquake at a Southern California Edison (SCE) station at Lucerne located 2 km from the fault. The six other SCE stations that recorded the Landers earthquake were located between 31 and 152 km from the fault (Hawkins and others, 1993).

An important set of records was obtained from the I-10/215 freeway overpass southwest of San Bernardino. The overpass instrumented is the connecting structure between I-10 from Los Angeles and I-215 toward San Bernardino. The bridge is a long and curved structure, typical of many in Southern California and similar to some which sustained heavy damage in the 1971 San Fernando earthquake. The bridge, about 2540 feet long and 90 feet high near the center, was recently strengthened by Caltrans and instrumented with 34 sensors by CSMIP. The ground motion near the bridge was 0.09 g. Higher accelerations (0.82 g) were recorded on the bridge deck. The motion at the footing of Bent

8 (channel 24) and at the deck level above Bent 8 (channel 20) are shown in Figure 9. Preliminary interpretation of the many spikes on some of the records indicate relative motion of the decks across the hinges (Malhotra and others, 1993). This is the first significant record from this type of bridge in California.

Four CSMIP stations located in the Los Angeles basin at an epicentral distance of approximately 165 km have peak displacements near 20 cm (8 inches). The peak accelerations at these stations are quite small (7% g and less). Large values of displacement despite the low levels of ground acceleration is a significant aspect of the records in the Los Angeles basin and may have contributed to the damage sustained by structures in the basin.

Strong-motion accelerograms were recorded at 132 CSMIP stations after the Big Bear earthquake. The epicentral distance of the stations ranges from 11 km for the closest (Big Bear Lake) to about 180 km for the farthest (Santa Felicia Dam). At the 132 CSMIP stations that recorded the Big Bear earthquake, a total of 218 records were obtained from over 950 strong-motion sensors. The 132 stations include 79 ground-response stations and 53 extensively-instrumented structures. The instrumented buildings included 4 that have been seismically isolated. The largest ground acceleration recorded by CSMIP ground-response stations was 0.57 g horizontal and 0.21 g vertical at Big Bear Lake (see Figure 7). The largest accelerations recorded on structures were 0.75 g recorded at a concrete tilt-up building and 1.02 g at the San Bernardino - I-10/215 Interchange.

ADDITIONAL STRONG-MOTION DATA

Several agencies in addition to CSMIP have strong-motion instruments in California. The U.S. Geological Survey maintains instruments of its own and of other agencies throughout the state (USGS, 1992a, 1992b). The University of Southern California maintains a network of 80 ground-response stations in southern California. In addition to these stations, smaller groups of stations are maintained by California Institute of Technology, Southern California Edison, Pacific Gas & Electric and other agencies. Finally, many private building owners in the City of Los Angeles have instruments in their buildings, as required by the City code.

ACKNOWLEDGEMENTS

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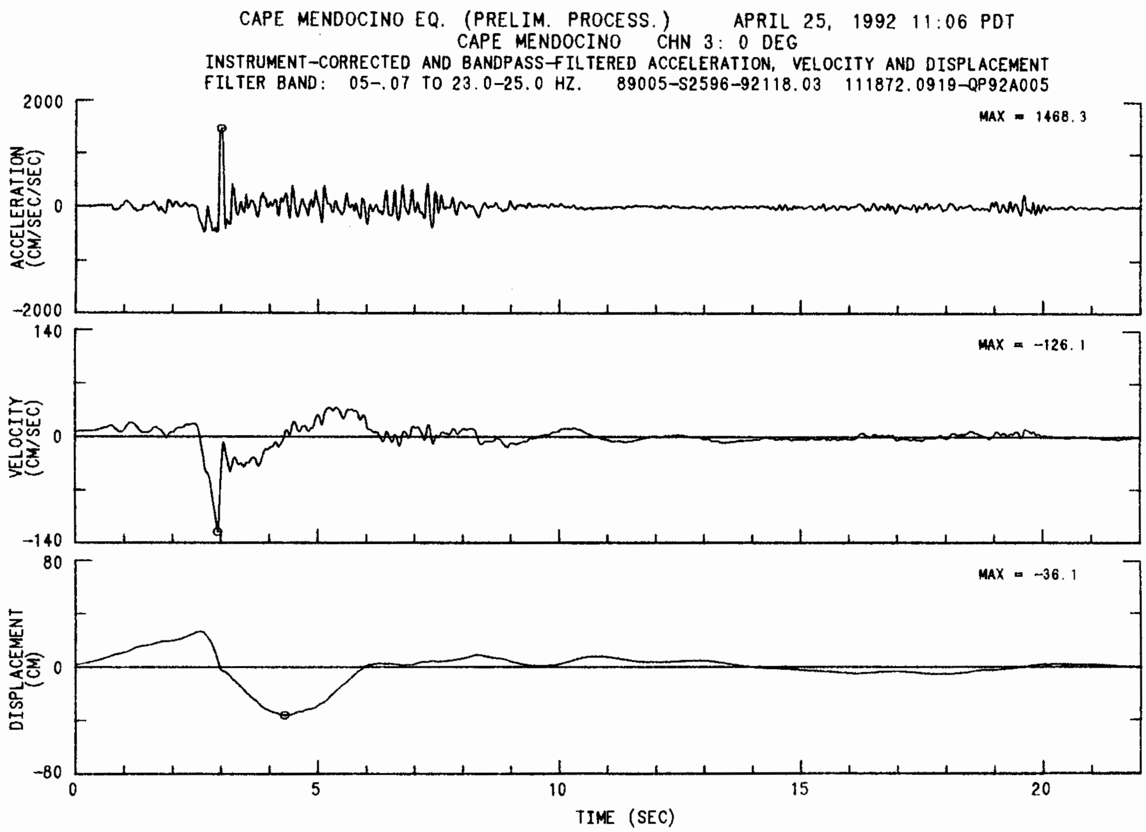

Figure 1: Acceleration, velocity and displacement time-histories (instrument-corrected and band-pass filtered) for the north-south component at the Cape Mendocino station.

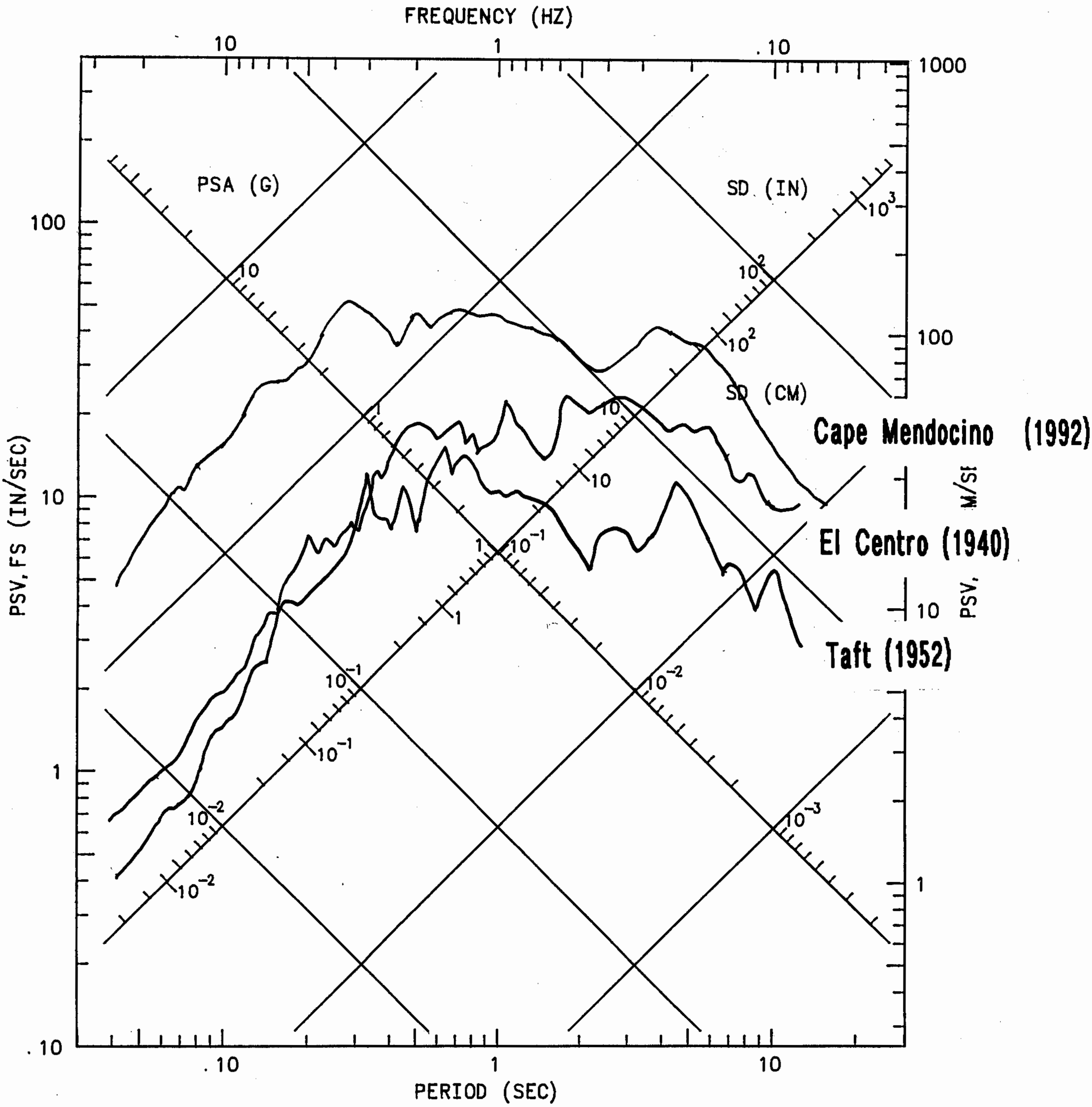

Figure 2: 5% damped response spectra from the Cape Mendocino station (1992 Cape Mendocino mainshock), Taft (1952 Kern County earthquake) and El Centro (1940 Imperial Valley earthquake).

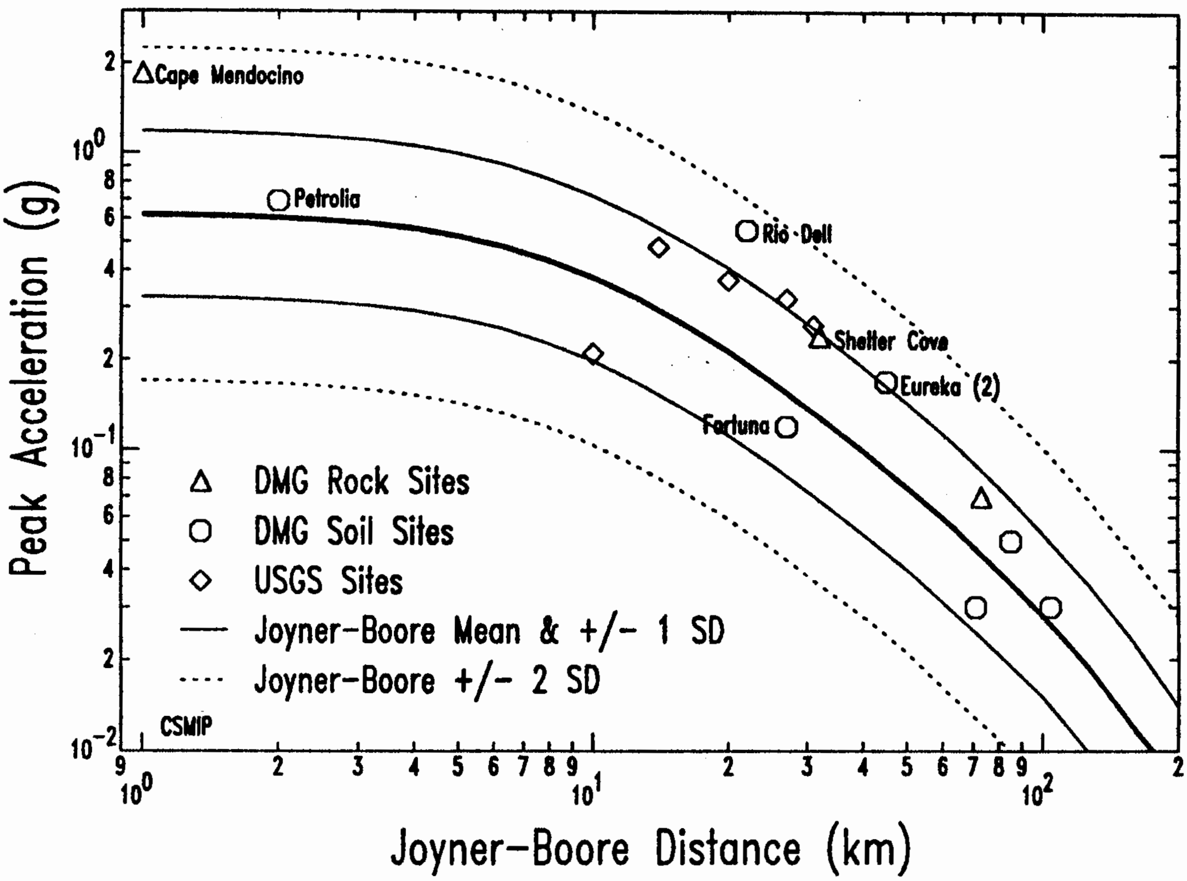

Figure 3: Peak horizontal acceleration versus distance for the Cape Mendocino mainshock. Distance measured from the surface projection of the aftershock zone to the station as defined by Joyner and Boore (1988). Largest of the two horizontal components is plotted. Bold solid curve is the median curve of Joyner and Boore (1988) for a magnitude 7.0 earthquake. Light solid lines indicate $\pm$ 1 standard deviation. Dashed lines indicate $\pm$ 2 standard deviations. Triangles indicate CSMIP stations located on rock; hexagons, on alluvium; diamonds indicate USGS stations.

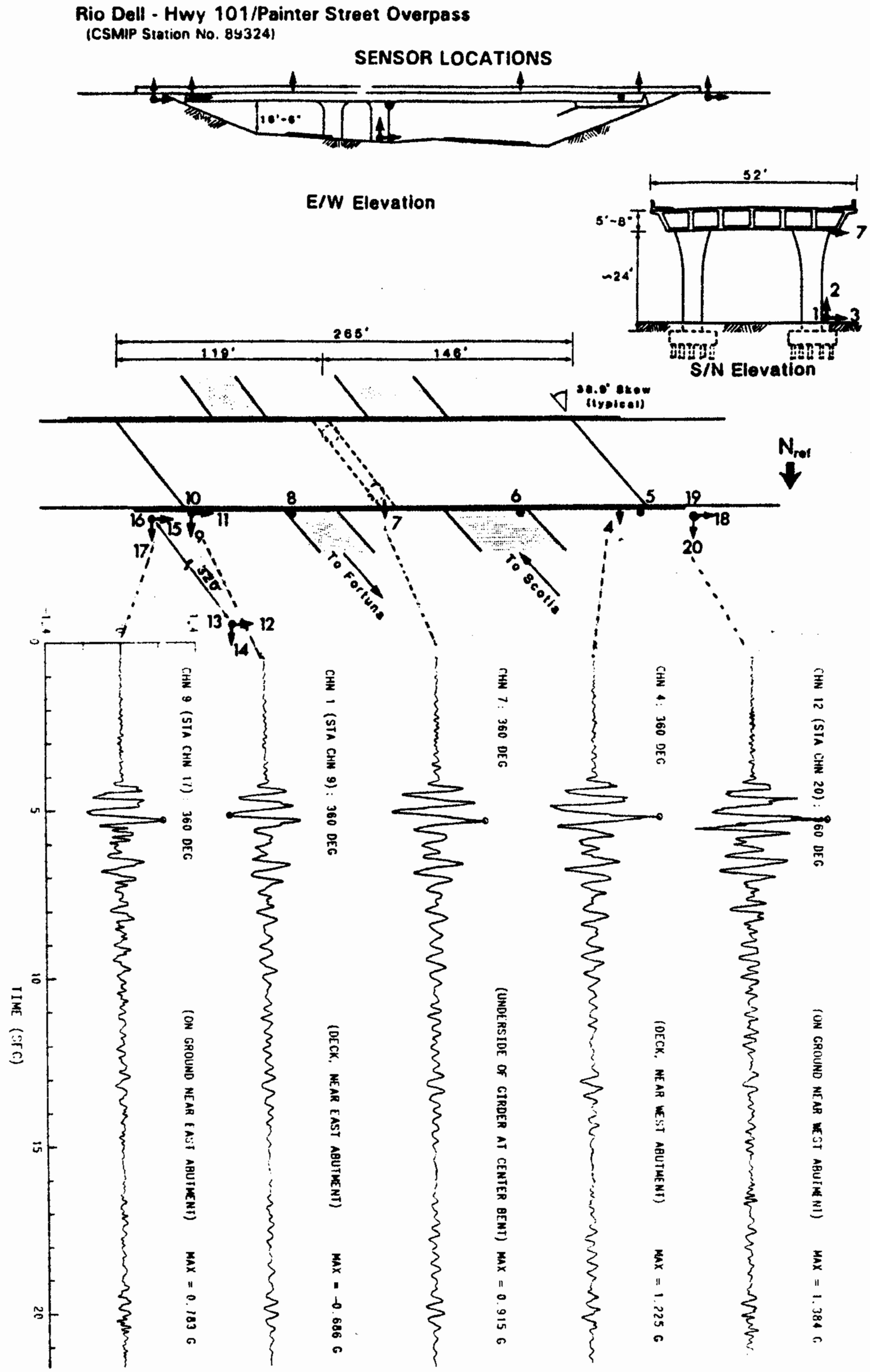

Figure 4: Sensor locations for the Rio Dell - Hwy 101/Painter Street Overpass. Accelerograms at five locations show the transverse motion of different parts of the bridge structure during the 1992 Cape Mendocino mainshock.

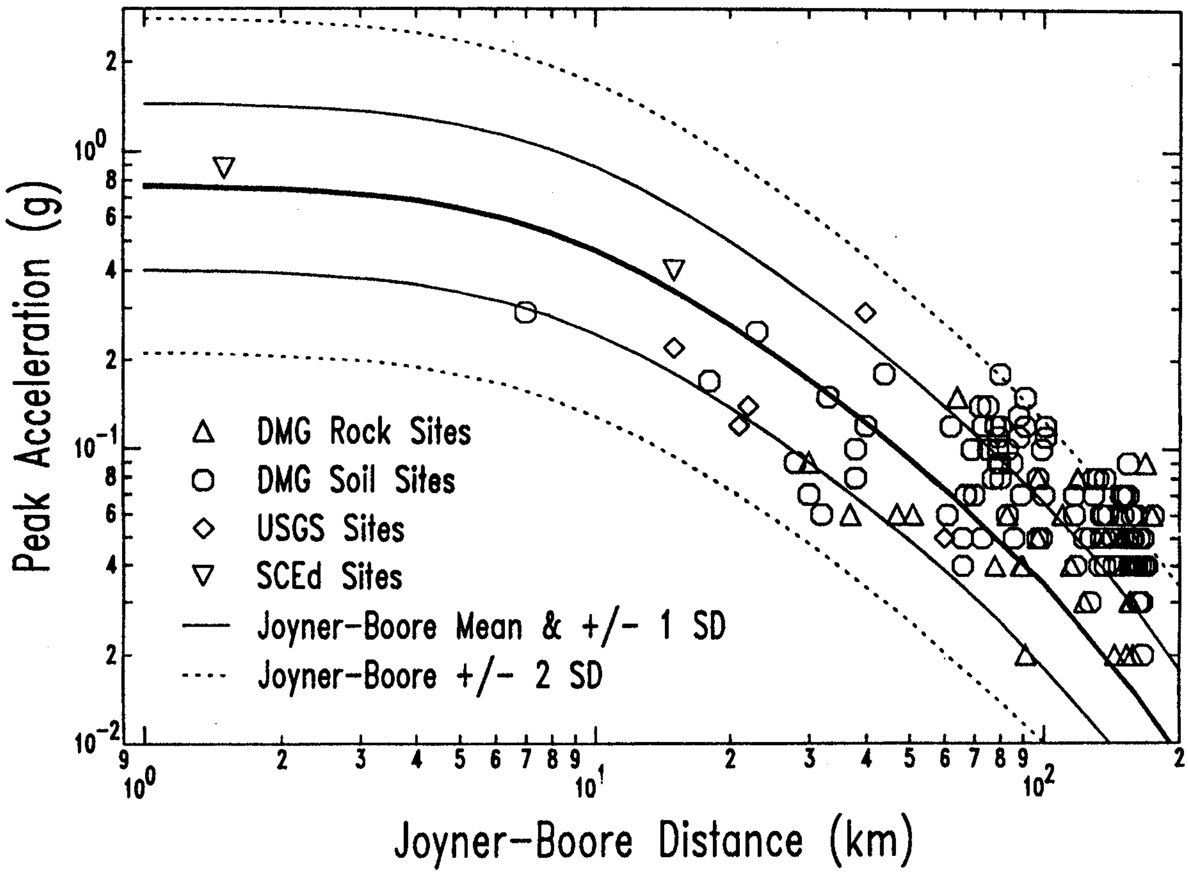

Figure 5: Peak horizontal acceleration versus distance for the Landers earthquake. Distance measured from the surface rupture to the station as defined by Joyner and Boore, 1988. Largest of the two horizontal components is plotted. Bold solid curve is the median curve of Joyner and Boore (1988) for a magnitude 7.3 earthquake. Light solid lines indicate $\pm$ 1 standard deviation. Dashed lines indicate $\pm$ 2 standard deviations. Triangles indicate CSMIP stations located on rock; hexagons, on alluvium; diamonds indicate USGS stations; inverted triangles indicate Southern California Edison stations.

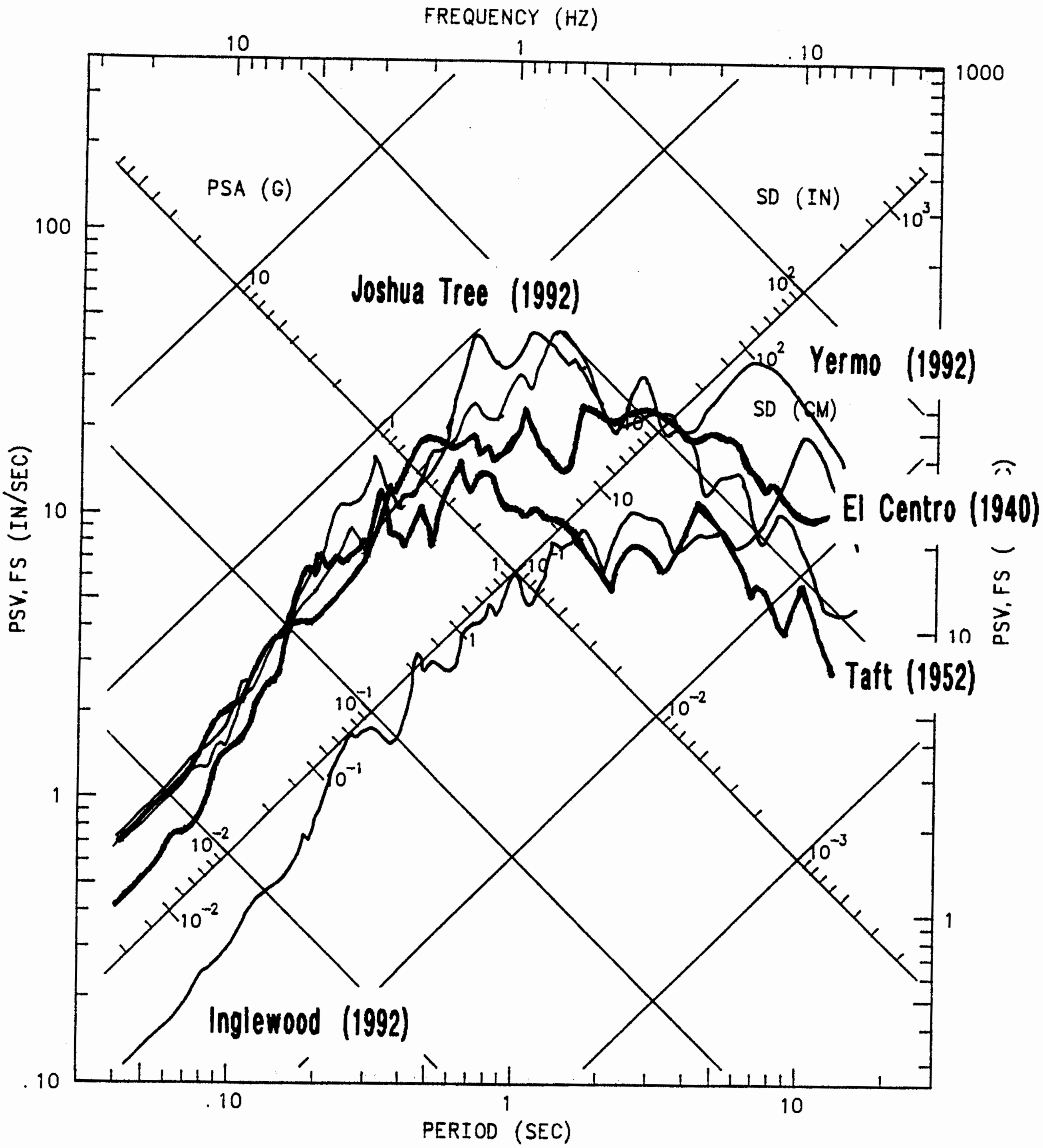

Figure 6: The 5% damped response spectra from the Joshua Tree, Yermo and Inglewood stations (1992 Landers earthquake) are shown by thin lines. The 5% damped response spectra from Taft (1952 Kern County earthquake) and El Centro (1940 Imperial Valley earthquake) are shown by thick lines.

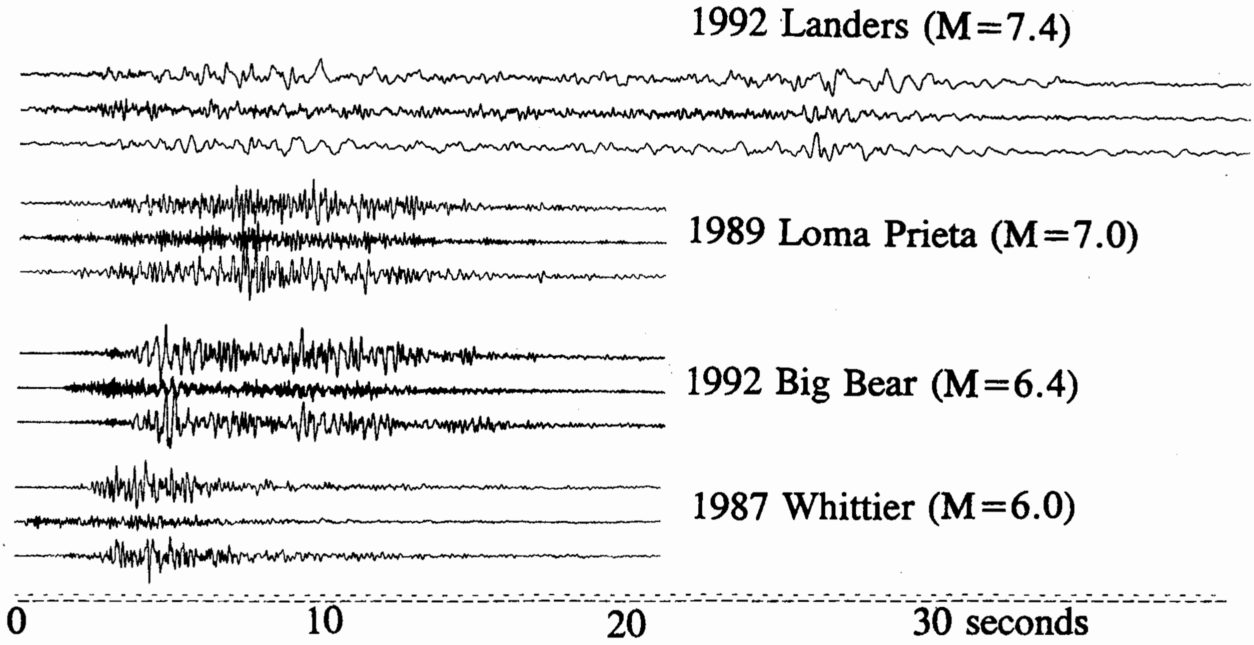

Figure 7: Duration of strong ground shaking. Accelerograms recorded for 4 different magnitude earthquakes at stations with similar distances (10 - 20 km).

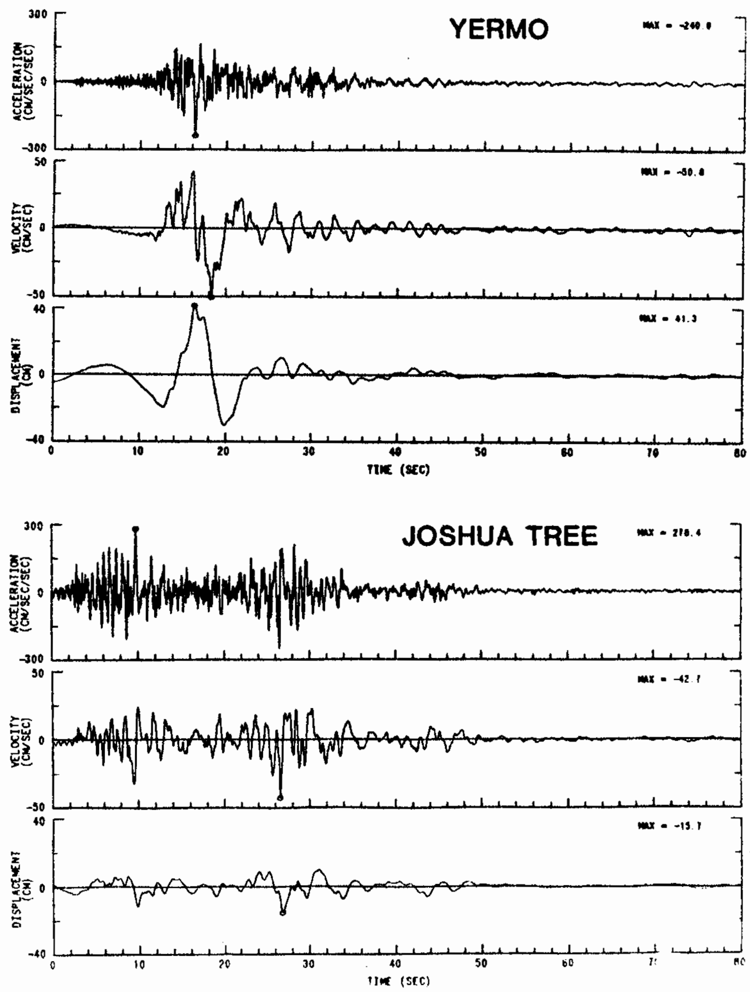

Figure 8: Comparison of Yermo and Joshua Tree acceleration, velocity and displacement waveforms (instrument-corrected and band-pass filtered) from the Landers earthquake.

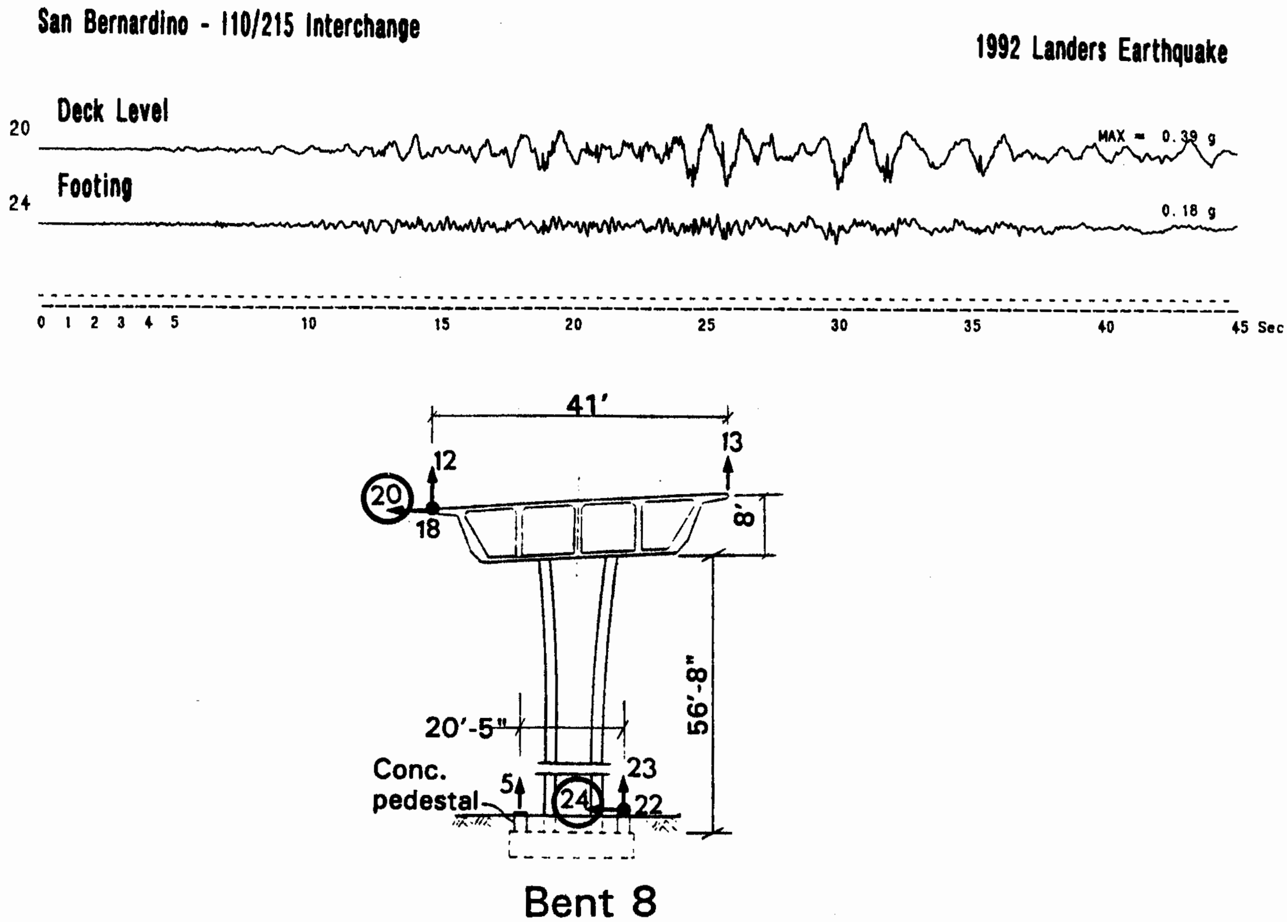

Figure 9: Two accelerograms recorded at the I-10/215 Interchange near San Bernardino. The channels show the motion at the footing of Bent 8 (channel 24) and at the deck level above Bent 8 (channel 20). A total of 34 acceleration channels are recorded at this structure.