SQUG

June 27, 2000

Ronald W. Hernan
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Subject: Procedure for Gathering and Validating Earthquake Experience Data - Revision 2 to Appendix A Containing Ten Examples of Ground Motion Estimate Derivations

Dear Mr. Hernan:

In our letter dated February 17, 2000, we forwarded to you for review and approval Revision 1 of the Procedure for Gathering and Validating Earthquake Experience Data. This procedure included an Appendix A which illustrated, with three examples, how SQUG is applying this procedure to develop ground-motion response spectra at individual database sites. Based on discussions between SQUG and NRC representatives, we understand that the NRC staff would like to have additional example ground motion estimate derivations submitted to further test the method and support their complete review of the subject procedure.

We are submitting Revision 2 to Appendix A of the subject procedure. As requested, it now includes a total of ten (10) examples of ground motion estimate derivations, i.e., the original three examples plus an additional seven. The pages in the body of the subject procedure (pages 1 and 7) which have changed as a result of this revision to Appendix A are also included in the enclosure.

As we indicated in our February 17, 2000 letter, SQUG intends to use the subject procedure to gather and validate earthquake experience data and add these data to the SQUG Earthquake Experience Database without additional formal NRC review. The review and approval process included in the enclosed procedure will serve to ensure that new data are suitable for use for seismic verification. Use of this procedure will result in a burden reduction in both utility submittal preparation and NRC review time. The approved procedure will also promote a consistent approach to collecting this data.

YE01
ADD: Ron Hernan
to Erids

Rec'd at DCD from
Ron Hernan on 9/20/00.

We trust this information is responsive to your request and will support your prompt review of the complete procedure.

Sincerely,

John M. Richards

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Enclosure

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Enclosure to
SQUG Letter Dated
June 27, 2000

PROCEDURE FOR GATHERING AND VALIDATING EARTHQUAKE EXPERIENCE DATA

REVISION 2

1.0 PURPOSE

The purpose of this procedure is to document the process that has been used by the Seismic Qualification Utility Group (SQUG) for collection, evaluation and validation of earthquake experience data which are contained in the SQUG Electronic Earthquake Experience Database (Reference 1).

This procedure also documents the process to be used in the future by SQUG to collect, evaluate and validate earthquake experience data as requested in Reference 2.

The continual advancement in the understanding of seismic behavior of structures, systems, and components is essential for safe and reliable engineering. Consequently, a controlled process that allows for the systematic collection of seismic experience data is an expected and essential element.

2.0 BACKGROUND

Earthquake experience data form the underlying backbone for much of the methodology SQUG developed to resolve the USI A-46 issue (Reference 3). The collection of earthquake experience data has been a collaborative effort between EQE International, SQUG and the Electric Power Research Institute (EPRI). An initial data collection effort in 1981-1982 was documented in Reference 4. This was reviewed by NRC, and the level of information provided was found sufficient for the earthquake experience-based approach in NUREG-1030 (Reference 5). Further data were collected in 1982-1985 for use by the Senior Seismic Review and Advisory Panel (SSRAP). These data, and the procedure used to collect them, were documented in the Twenty Classes Report (Reference 6). The SSRAP review of these data was documented in the SSRAP Report (Reference 7). NRC review of the SSRAP Report was documented in Reference 2.

Collection of earthquake experience data continued after 1985. The procedure for collecting and documenting the data was the same as that reported in References 4 and 6. In 1993, an electronic database of the earthquake data was developed. The current version of this database is described in Reference 1. Copies of this report, and the electronic database itself, were submitted for NRC review in May, 1998 (Reference 8).

3.0 SEISMIC EXPERIENCE ELECTRONIC DATABASE

The seismic experience electronic database contains data on equipment from 124 facilities (sites) located in the strong-motion areas of 24 earthquakes that have occurred excluded from consideration until sufficiently accurate geotechnical and/or geological data can be obtained.

When an adjustment to the recorded response spectrum is required because its Soil Profile Type is different than that of the database site, this adjustment will be based on one or more of the following as appropriate: (1) empirical site factors derived from a set of appropriate spectral attenuation relationships, (2) site factors recommended in the *UBC* and *NEHRP Recommended Provisions*, and (3) other site factors derived from special empirical, theoretical, or laboratory studies. When an adjustment to the recorded response spectrum is required because its sediment depth is different than that of the database site, this adjustment will be based on empirical correlations between spectral acceleration and sediment depth.

Ten example ground motion estimates are provided in Appendix A.

4.3 Treatment of Damage, Failures and Anomalies

As noted in Section 4.1, any equipment anomalies, damage, or failures receive a focused investigation during the data collection effort. A "root cause" evaluation is prepared which either (1) concludes that existing SQUG caveats would prevent the noted equipment damage, or failure anomaly, or (2) recommends additional SQUG caveats applicable for the equipment class with the observed equipment anomaly, damage, or failure to ensure that the observed effect is addressed in SQUG walkdown procedures. If warranted, the GIP will be revised after appropriate review by peer review groups as presented in Reference 9 and approved for use by the NRC in Reference 10.

4.4 Experience Data Screening and Documentation

The raw data that is collected following an earthquake database site investigation is organized and screened prior to entry into the electronic database. The data is reviewed to ensure that enough information exists on each equipment component to meet minimum standards for database inclusion. Components with unexplained anomalies, damage or failures are placed on a list for further investigation. By the time a new piece of equipment is entered into the database it has:

- Photographs
- Written description of the component
- Make, model number and operating status
- Location in structure
- Anchorage and load path description
- Pertinent sketches, catalog cuts, drawings
- Resolution on any problems experienced in the seismic event

Appendix A

Examples of Ground Motion Estimate Derivations

This attachment documents the development of earthquake response spectra for the following ten SQUG database earthquake-facility pairs.

No.	Site	Earthquake
1	PALCO Cogeneration Plant Scotia, California	1992 Petrolia
2	Great Western Financial Data Center Northridge, California	1994 Northridge
3	Placerita Cogeneration Plant Newhall, California	1994 Northridge
4	Power Generation Facilities Island of Guam	1993 Guam
5	Whitewater Hydroelectric Plant Banning, California	1986 North Palm Springs
6	IBM Santa Teresa Facility HVAC San Jose, California	1984 Morgan Hill
7	UCSC Central Campus Santa Cruz, California	1989 Loma Prieta
8	Santa Cruz Water Treatment Plant Santa Cruz, California	1989 Loma Prieta
9	Calpine Gilroy Cogeneration Plant Gilroy, California	1989 Loma Prieta
10	Watkins-Johnson Instrument Plant Scotts Valley, California	1989 Loma Prieta

A.1 PALCO Cogeneration Plant (Scenario 2)

The PALCO Cogeneration Plant is located in the town of Scotia in Humboldt County, California. It is located directly over the rupture plane of the April 25, 1992 moment-magnitude (M_w) 7.0 Petrolia (Cape Mendocino) earthquake.

The Petrolia earthquake caused widespread damage throughout the Cape Mendocino region (Reagor and Brewer, 1992). It was assigned a maximum intensity of VIII on the Modified Mercalli Intensity (MMI) scale. Shaking effects consistent with MMI VIII were observed in Ferndale, Petrolia, Honeydew, Rio Dell, and Scotia. The mainshock was followed by two large aftershocks on April 26.

A.1.1 Strong-Motion Recordings

There was no strong-motion recording at the PALCO Plant. The closest recording to the Plant was 2.3 kilometers away at the Highway 101–Painter Street Overpass in the town of Rio Dell (CSMIP Station #89324). The geographic coordinates of the recording site are 40.503°N latitude and 124.100°W longitude. The free-field accelerograph, which is located in an instrument shelter adjacent to the bridge, recorded peak ground accelerations of 0.55*g*, 0.39*g*, and 0.20*g* in the North, West, and Vertical directions, respectively (Shakal and others, 1992). The 5%-damped acceleration response spectra for the two horizontal components (Darragh and others, 1992) are shown in Figure A-1.

A.1.2 Earthquake Parameters

Oppenheimer and others (1993) report the following seismological parameters for the April 25 Petrolia mainshock:

Date:	April 25, 1992
Time:	18:06:05 Greenwich Mean Time (GMT)
Magnitude:	7.0 M_w
Epicenter:	40.332°N, 124.228°W
Depth:	10.6 km
Strike:	350° (northwest)
Dip:	13° to the northeast
Rake:	106° (predominantly thrust)

Similar source mechanisms were obtained by the U.S. Geological Survey (1992), Murray and others (1996), and Graves (1994).

Using strong-motion recordings, Graves (1994; written communication, 1994) determined the following rupture model for the earthquake:

Width (down-dip):	20 km
Length:	28 km
Depth to Top:	6.3 km
Strike:	350° (northwest)
Dip:	14° to the northeast
Rake:	90° to 105° for asperities (predominantly thrust) 115° to 140° for shallow southern part (oblique slip)
Average Slip:	1.9 m
Seismic Moment:	2.51×10^{26} dyne-cm

The seismic moment of 2.51×10^{26} dyne-cm is consistent with a moment magnitude of 6.9 based on the moment-magnitude relationship of Hanks and Kanamori (1979).

The following distances from the PALCO and recording sites to the rupture plane of the Petrolia earthquake were calculated from the above rupture model and the epicentral coordinates determined by Oppenheimer and others:

Site	Epicentral Distance (km)	Azimuth (°)	Surface Distance (km)	Rupture Distance (km)
PALCO Plant	19.8	33	7.3	13.3
CSMIP #89324	21.9	30	7.9	13.6

In this table, Rupture Distance is the shortest distance between the site and the seismogenic part of the rupture plane of the earthquake, Surface Distance is the shortest distance between the site and the surface projection of this rupture plane, and Azimuth is the angle between the epicenter and the site measured clockwise from north.

A.1.3 Local Site Conditions

Shakal and others (1992) describe the recording site as being underlain by 15 meters of alluvium. Heuze and Swift (1991) estimate the shear-wave velocity of the soil beneath the recording site to a depth of about 10 meters to be approximately 200 m/s. There is no similar geotechnical data available for the PALCO Plant. However, a 1:62,500 scale geologic map of the area (Ogle, 1953) indicates that both sites are located on relatively thin, young (Holocene) stream terrace deposits within the Eel River Valley. The terrace deposits are composed of gravel, sand, silt, and clay, with gravel predominating. The Upper Pliocene Rio Dell Formation underlies the terrace deposits to a depth of several kilometers. Massive mudstone, alternating thin sandstone and mudstone, phantom-banded mudstone, and very fine-grained sandstone are the principal lithologic units of the Rio Dell Formation.

Based on the above information, both sites can be classified as Soil Profile Type S_D (Stiff Soil Profile) based on the site classifications given in the 1997 *Uniform Building Code* (UBC) (ICBO, 1997). This Soil Profile Type has a shear-wave velocity in the top 30 meters that ranges between 180 and 360 m/s. Based on the above information, it can be concluded that both the Plant and recording sites have similar soil-amplification characteristics.

A.1.4 Recommended Response Spectra

Based on the proximity of the PALCO Plant to the Rio Dell recording (2.3 kilometers), the similar distance from both sites to the rupture plane of the Petrolia earthquake (13.3 and 13.6 kilometers), the similar epicentral azimuths of the two sites (30° and 33°), and the similar soil-amplification characteristics at both sites, it is believed that the Rio Dell recording can be used as a credible estimate of the ground motion at the PALCO Cogeneration Plant. The recommended 5%-damped acceleration response spectrum is shown in Figure A-2. This response spectrum is identical to that recommended by Boore (1997) for the same site.

A.2 Great Western Financial Data Center (Scenario 3)

The Great Western Financial Data Center is located in the city of Northridge in the San Fernando Valley, Los Angeles County, California. It is located directly over the rupture plane of the January 17, 1994 moment magnitude (M_w) 6.7 Northridge earthquake.

The Northridge earthquake caused widespread damage throughout the Los Angeles region (Dewey and others, 1995). It was assigned a maximum intensity of IX on the Modified Mercalli Intensity (MMI) scale. Shaking effects consistent with MMI IX were observed in Sherman Oaks, Northridge, Granada Hills, along the I-5 corridor just east of the Santa Susana Mountains, and in two neighborhoods of several blocks each in Santa Monica and west-central Los Angeles. Shaking effects consistent with MMI VIII were observed at many locations over a broad area of the San Fernando Valley, and also in parts of Santa Clarita Valley, Simi Valley, Santa Monica, west-central Los Angeles, Fillmore, the University of Southern California/County Hospital complex in Los Angeles, and in a 3-kilometer long, several blocks wide, area of Hollywood along Hollywood Boulevard.

A.2.1 Strong-Motion Recordings

A single strong-motion recording was obtained on the roof of the Financial Data Center. There was no ground-level recording at the Data Center. There were, however, eleven ground-level recordings within 10 kilometers of the Center. The closest three recordings are on Roscoe Boulevard in Northridge. (LA Code #C130, 2.8 kilometers), Topanga Canyon Boulevard in Canoga Park (USC #53, 5.1 kilometers), and Saticoy Street in Northridge (USC #3, 5.5 kilometers). All three recordings are located close enough to the Financial Data Center to have experienced the same level of ground shaking and earthquake source effects.

The other eight recordings that were located within 10 kilometers of the Data Center are not considered to be representative of the ground-shaking at the Center for the following reasons. They were either too far from the Center (i.e., greater than 8 kilometers), they were founded on significantly different geological deposits, or they experienced significant source directivity effects. These latter effects were particularly important for recordings located northeast of the Data Center in the direction of rupture propagation (see the discussion on source characteristics below).

Darragh and others (1995) and Trifunac and others (1994) give a detailed description of the three selected recordings. A summary of this information is provided in the following table.

Parameter	LA Code #130	USC #53	USC #3
Structure	7-story bldg.	1-story bldg.	2-story bldg.
Location	Ground level	Ground level	Ground level
Latitude	34.217°N	34.212°N	34.209°N
Longitude	118.553°W	118.606°W	118.517°W
PGA (g)	0.42 (North) 0.41 (West) 0.35 (Up)	0.39 (S16W) 0.35 (S74E) 0.42 (Up)	0.45 (South) 0.33 (East) 0.80 (Up)

The two horizontal components of the 5%-damped acceleration response spectra of the three selected recordings are shown in Figures A-3 to A-5.

A.2.2 Earthquake Parameters

Scientists of the U.S. Geological Survey and the Southern California Earthquake Center (1996) report the following seismological parameters for the Northridge earthquake:

Date:	January 17, 1994
Time:	12:30 Greenwich Mean Time (GMT)
Magnitude:	6.7 M_w
Epicenter:	34.209°N, 118.541°W
Depth:	19 km
Strike:	280° to 290° (northwest)
Dip:	35° to 45° to the southwest
Mechanism:	Thrust

Similar source parameters were obtained by many other seismologists (e.g., *Bulletin of the Seismological Society of America*, 1996). According to these studies, the rupture initiated at the hypocenter in the southeast corner of the rupture plane and propagated up-dip to the north and northeast where the largest subevent occurred.

Using strong-motion, teleseismic, GPS, and leveling data, Wald and others (1996) determined the following rupture model for the earthquake:

Width (down-dip):	21 km
Length:	14 km
Depth to Top:	6 km
Strike:	122° (southeast)
Dip:	40° to the southwest)
Average Rake:	101° (thrust)
Average Slip:	1.3 m

Seismic moment:	$1.3 \pm 0.2 \times 10^{26}$ dyne-cm (6.7 M_w)
Avg. Stress Drop	74 bars

The seismic moment of 1.3×10^{26} dyne-cm is consistent with a moment magnitude of 6.7 based on the moment-magnitude relationship of Hanks and Kanamori (1979).

The following distances from the recording and Data Center sites to the rupture plane of the Northridge earthquake were calculated from the above rupture model and the epicentral coordinates determined by Scientists of the U.S. Geological Survey and the Southern California Earthquake Center (1996):

Site	Epicentral Distance (km)	Azimuth (°)	Surface Distance (km)	Rupture Distance (km)
Data Center	4.1	330	0.0	12.6
LA Code #C130	1.4	309	0.0	13.8
USC #53	6.0	273	1.4	15.8
USC #3	2.2	90	0.0	13.2

In this table, Rupture Distance is the shortest distance between the site and the seismogenic part of the rupture plane of the earthquake, Surface Distance is the shortest distance between the site and the surface projection of this rupture plane, and Azimuth is the angle between the epicenter and the site measured clockwise from north.

A.2.3 Local Site Conditions

There are no reliable site-specific geotechnical data available for the Financial Data Center or the three recording sites. However, a geologic map of the area (Yerkes and Campbell, 1993) indicates that the Data Center and the USC #53 site are located on Holocene alluvium up to 30-meters thick and that the LA Code #C130 and USC #3 sites are located on Late Holocene alluvium up to 3-meters thick overlain by Holocene alluvium. Since it is likely that the buildings that house the accelerographs have foundations that are at least a few meters deep, any remaining Late Holocene deposits, if present at all, are too thin to have affected the recorded ground motions at frequencies less than about 25 Hz. Underlying the Holocene alluvium is a sequence of Quaternary, Tertiary, and Cretaceous sediments at least 1 to 2 kilometers thick.

Shear-wave velocity measurements were conducted at the USC recording stations using the CXW method. This method uses surface-wave dispersion to infer the shear-wave velocity profile beneath the site. However, Boore and Brown (1998) and Wills (1998) have shown that the CXW method can lead to estimates of shear-wave velocity that are significantly different from those obtained using more traditional down-hole and cross-hole techniques. Based on this conclusion, the CXW-based measurements were not used.

Instead of relying on direct shear-wave velocity measurements, the average shear-wave velocity in the top 30 meters of the Holocene alluvium that underlies the Data Center and the three recording sites was estimated from the shear-wave velocity characteristics determined for different geologic units in California by Wills and Silva (1998). According to this assessment, all four sites can be classified as Soil Profile Type S_D (Stiff Soil Profile) based on the soil classifications given in the 1997 *Uniform Building Code* (UBC) (ICBO, 1997). This Soil Profile Type has a shear-wave velocity in the top 30 meters that ranges between 180 and 360 m/s. Based on the above information, it can be concluded that the Data Center and the three recording sites have similar soil-amplification characteristics. The similarity in both the amplitude and shape of the response spectra from the three nearby recordings lends further empirical justification to this conclusion.

A.2.4 Recommended Response Spectrum

All of the recordings are located on the ground floor of 1-story to 7-story buildings. As a result, they are likely to be somewhat deficient in high-frequency ground motions due to wave-scattering and wave-passage effects. Further justification for these kinematic SSI effects can be found by comparing the response spectrum for the LA Code #C130 recording, which was obtained in a 7-story building, with the two USC recordings, which were obtained in smaller 1-story and 2-story buildings (Figure A-6). The LA Code #C130 spectrum is found to be lower than the two USC spectra between frequencies of about 4 and 13 Hz. As a result, the selected recordings, and especially the LA Code #C130 recording, are considered to be a conservative (i.e., lower) estimate of the high-frequency amplitude of the free-field spectra at each of these sites.

The three selected recordings are all located southeast and southwest of the Financial Data Center. A contour map of the 0.24-second spectral velocity developed by the SAC Joint Venture Partnership (1995) suggests that short-period spectral amplitudes from the Northridge earthquake increased from south to north across the San Fernando Valley. This suggests that the actual ground motion at the Data Center is likely to have been somewhat higher than indicated by these recordings.

Based on the proximity of the Financial Data Center to the three selected recordings (2.8 to 5.5 kilometers), the similar distance from each of the sites to the rupture plane of the Northridge earthquake (12.6 to 15.8 kilometers), the similar location of all of the sites with respect to the rupture plane of the earthquake, the similar amplitude and spectral shapes of the three recorded response spectra (Figure A-6), and the similar soil-amplification characteristics at each of the sites, it can be concluded that the average of the LA Code #C130, USC #3, and USC #53 response spectra can be used as a credible, although somewhat conservative (i.e., lower), estimate of the ground motion at the Great Western Financial Data Center. The recommended 5%-damped acceleration response spectrum is shown in Figure A-7.

Boore (1997) used three entirely different recordings to estimate a response spectrum at the Financial Data Center from the Northridge earthquake. The recordings he used were from the 7-story Hotel in Van Nuys (CSMIP #24386), the Sepulveda VA Hospital in Los Angeles (USGS #637), and the Rinaldi Receiving Station in Mission Hills (LADWP SMA-1 #5968). The latter two recordings were located northeast of the Data Center in the direction of rupture propagation. As a result, the ground motion at these two sites were likely to be larger than those located closer to the Center. For example, the horizontal peak accelerations at the Sepulveda VA Hospital were 0.94*g* and 0.74*g* and those at Rinaldi Receiving Station were 0.84*g* and 0.49*g*, significantly higher than those recorded at the three sites selected in this study.

The SAC Joint Venture Partnership (1995) also estimated ground motions from the Northridge earthquake for a site very close to the Great Western Financial Data Center (their Site 4). A comparison of the recommended response spectrum in Figure A-7 with that estimated by the SAC Joint Venture Partnership (1995) indicates that the SAC spectrum is higher, especially at high frequencies, than that recommended in this study. For example, SAC calculated peak accelerations of 0.71*g* (North) and 0.49*g* (South) for Site 4; whereas, a mean horizontal acceleration of 0.39*g* was estimated in the current study.

A.3 Placerita Cogeneration Plant (Scenario 3)

The Placerita Cogeneration Plant is located in the city of Newhall in the Santa Clarita Valley, Los Angeles County, California. It is located 4.0 kilometers north of the surface projection of the rupture plane of the January 17, 1994 moment magnitude (M_w) 6.7 Northridge earthquake.

The Northridge earthquake caused widespread damage throughout the Los Angeles region (Dewey and others, 1995). It was assigned a maximum intensity of IX on the Modified Mercalli Intensity (MMI) scale. Shaking effects consistent with MMI IX were observed in Sherman Oaks, Northridge, Granada Hills, along the I-5 corridor just east of the Santa Susana Mountains, and in two neighborhoods of several blocks each in Santa Monica and west-central Los Angeles. Shaking effects consistent with MMI VIII were observed at many locations over a broad area of the San Fernando Valley, and also in parts of Santa Clarita Valley, Simi Valley, Santa Monica, west-central Los Angeles, Fillmore, the University of Southern California/County Hospital complex in Los Angeles, and in a 3-kilometer long, several blocks wide, area of Hollywood along Hollywood Boulevard. An MMI of VIII was observed in the vicinity of the Placerita Plant

A.3.1 Strong-Motion Recordings

There was no strong-motion recording at the Placerita Plant. The closest recording was 2.8 kilometers away at the L.A. County Fire Station in the city of Newhall (CSMIP Station #24279). The geographic coordinates of the recording site are 34.390°N latitude and 118.530°W longitude. The accelerograph, which is located in a one-story building, recorded peak ground accelerations of 0.61*g*, 0.63*g*, and 0.62*g* in the North, West, and Vertical directions, respectively (Shakal and others, 1994). The 5%-damped acceleration response spectra for the two horizontal components (Darragh and others, 1994) are shown in Figure A-8.

A.3.2 Earthquake Parameters

Scientists of the U.S. Geological Survey and the Southern California Earthquake Center (1996) report the following seismological parameters for the Northridge earthquake:

Date:	January 17, 1994
Time:	12:30 Greenwich Mean Time (GMT)

Magnitude:	6.7 M_w
Epicenter:	34.209°N, 118.541°W
Depth:	19 km
Strike:	280° to 290° (northwest)
Dip:	35° to 45° to the southwest
Mechanism:	Thrust

Similar source parameters were obtained by many other seismologists (e.g., *Bulletin of the Seismological Society of America*, 1996). According to these studies, the rupture initiated at the hypocenter in the southeast corner of the rupture plane and propagated up-dip to the north and northeast where the largest subevent occurred.

Using strong-motion, teleseismic, GPS, and leveling data, Wald and others (1996) determined the following rupture model for the earthquake:

Width (down-dip):	21 km
Length:	14 km
Depth to Top:	6 km
Strike:	122° (southeast)
Dip:	40° to the southwest
Average Rake:	101° (thrust)
Average Slip:	1.3 m
Seismic moment:	$1.3 \pm 0.2 \times 10^{26}$ dyne-cm (6.7 M_w)
Avg. Stress Drop	74 bars

The seismic moment of 1.3×10^{26} dyne-cm is consistent with a moment magnitude of 6.7 based on the moment-magnitude relationship of Hanks and Kanamori (1979).

The following distances from the recording and Placerita sites to the rupture plane of the Northridge earthquake were calculated from the above rupture model and the epicentral coordinates determined by Scientists of the U.S. Geological Survey and the Southern California Earthquake Center (1996):

Site	Epicentral Distance (km)	Azimuth (°)	Surface Distance (km)	Rupture Distance (km)
Placerita Cogen	19.3	11	4.0	7.2
CSMIP #24279	20.1	3	3.7	7.0

In this table, Rupture Distance is the shortest distance between the site and the seismogenic part of the rupture plane of the earthquake, Surface Distance is the shortest distance between the site and the surface projection of this rupture plane, and Azimuth is the angle between the epicenter and the site measured clockwise from north.

A.3.3 Local Site Conditions

Both the Placerita Cogeneration Plant and the Newhall recording are located within Placerita Canyon at the southern end of the Santa Clarita Valley. The Newhall site is located near the mouth of the canyon, whereas the Placerita Plant is located within the canyon itself. There are no reliable site-specific geotechnical data available for either site. However, a geologic map of the area (Yerkes and Campbell, 1995) indicates that both sites are located on Quaternary alluvium. A 985-foot well located approximately 600 meters northwest of the Placerita site indicates that the Quaternary alluvium at this location is underlain by the Pleistocene Saugus Formation, which in turn is underlain by the Plio-Pleistocene Pico Formation. All 985 feet of the sediments encountered in the well are relatively unconsolidated. A 2379-foot well located approximately one kilometer west of the Newhall site encountered the same sequence of deposits.

The average shear-wave velocity in the top 30 meters of the Quaternary alluvium that underlies the Placerita and Newhall sites was estimated from shear-wave velocity characteristics determined for different geologic units in California by Wills and Silva (1998). According to this assessment, these two sites can be classified as Soil Profile Type S_D (Stiff Soil Profile) based on soil classifications given in the 1997 *Uniform Building Code* (UBC) (ICBO, 1997). This Soil Profile Type has a shear-wave velocity in the top 30 meters that ranges between 180 and 360 m/s. Based on the above information, it can be concluded that both the Plant and recording sites have similar soil-amplification characteristics.

A.3.4 Recommended Response Spectrum

The Newhall recording is located on the ground floor of a 1-story building. As a result, it is likely to be slightly deficient in high-frequency ground motions due to wave-scattering and wave-passage effects. Because of this, the selected recording is considered to be a conservative (i.e., lower) estimate of the high-frequency amplitude of the free-field spectrum at this site.

Based on the proximity of the Placerita Cogeneration Plant to the Newhall recording (2.8 kilometers), the similar distance from each of the sites to the rupture plane of the Northridge earthquake (7.0 and 7.2 kilometers), the similar azimuth from the epicenter of the earthquake to each of the sites (3° and 11°), and the similar soil-amplification characteristics at each of the sites, it can be concluded that the Newhall Fire Station recording can be used as a credible estimate of the ground motion at the Placerita Cogeneration Plant. The recommended 5%-damped acceleration response spectrum is shown in Figure A-9.

Boore (1997) also provided estimates of ground motion at the Placerita site. He used two different procedures for his estimates because he could not decide which might be more appropriate. For the first estimate he modified the Newhall Fire Station recording. For the second estimate he averaged the modified recordings from the Newhall Fire Station, the Jensen Generator Building, the Sylmar Converter Station, and the Sylmar County Hospital. Modifications were made to account for the estimated differences in shear-wave velocity among the sites, differences in the distance to the surface projection of the fault rupture, and the distance from the Placerita site to each of the recording sites. In both cases, his modifications lowered the high-frequency amplitudes from those recorded at the Newhall recording site. The additional three recordings used in his second estimate are further from the Placerita site and are not as relevant based on their location with respect to the fault rupture. It is believed that there is no solid scientific basis for modifying the recordings and that the Newhall Fire Station recording provides the best estimate of the ground motion at the Placerita Cogeneration Plant.

A.4 Guam Power Generating Facilities (Scenario 4)

The Guam Power Generating facilities are located on the Island of Guam, the largest and southernmost of the Marianas Island chain in the South Pacific. The island is approximately 48 kilometers long and between 6 and 19 kilometers wide. Guam is volcanic in origin. The southern end of the island is mountainous with altitudes ranging from 210 to 400 meters. The northern part of the island consists of a series of coral limestone terraces that are relatively flat and that range from about 60 to 180 meters in height.

The Guam power generating facilities consist of the Piti Power Plant and the Cabras Generating Station in the Apra Harbor area, and the Tanguisson, Yigo, and Dededo Generating Stations on the northern part of the island. According to the Earthquake Engineering Research Institute (1995), all of these facilities sustained some damage during the August 8, 1993 moment-magnitude (M_w) 7.7 Guam earthquake. The Apra Harbor facilities had the greatest amount of damage because of their location in an area of widespread ground-failure effects.

The power generating facilities are located several tens of kilometers northwest of the rupture plane of the Guam earthquake. According to the U.S. Geological Survey (1993) and the Earthquake Engineering Research Institute (1995), the earthquake caused extensive damage to hotels in the Tumon Bay area. Many structures in the Apra Harbor area were seriously damaged due to liquefaction and related ground failure. Minor damage was widespread on the island. A relatively small tsunami was generated and was noted at several locations in the South Pacific, including Japan and Hawaii, with no reported damage. The earthquake was assigned a maximum intensity of IX on the Modified Mercalli Intensity (MMI) scale. Shaking effects consistent with MMI VII were observed at several locations on the northern part of the island (U.S. Geological Survey, 1993).

A.4.1 Strong-Motion Recordings

The United States Navy maintained three strong-motion instruments on Guam at the time of the earthquake, but no records were recovered from these instruments because of malfunctions. However, the Earthquake Engineering Research Institute (1995) gives a qualitative estimate of the level of shaking on the island from an evaluation of liquefaction effects and damage to concrete bus stops. This evidence supports the conclusion that effective ground accelerations on the island probably ranged from about 0.15*g* to 0.25*g*.

A.4.2 Earthquake Parameters

The U.S. Geological Survey (1993) reports the following seismological parameters for the Guam earthquake:

Date:	August 8, 1993
Time:	08:24:25 Greenwich Mean Time (GMT)
Magnitude:	7.1 m_b, 8.0 M_s
Epicenter:	12.982°N, 144.801°E
Depth:	59 km
Strike:	255° (southwest)
Dip:	20° to the northwest
Rake:	90° (thrust)

From a complete study of P and SH body waves, Campos and others (1996) relocated the aftershocks and the subevents of the mainshock and proposed a relatively simple model for the rupture process of the event. Based on this analysis, they concluded that the earthquake ruptured a shallow-dipping thrust fault that corresponds to the subduction interface of the Pacific and Philippine Sea plates. Campos and others best single point-source model for the earthquake based on the inversion of teleseismically observed body waves is as follows:

Seismic Moment:	4.5×10^{27} dyne-cm
Centroid Depth:	41.5 km
Strike:	241.67° (southwest)
Dip:	13.77° to the northwest
Rake:	84.91° (predominantly thrust)

The moment magnitude (M_w) given by this inversion is 7.7 according to the moment-magnitude relationship of Hanks and Kanamori (1979). The fault plane solutions reported by Dziewonski and others (1994), the U.S. Geological Survey (1993), and the California Institute of Technology (Caltech) are all quite different from each other and from the solution given above. Campos and others show that their solution is statistically superior to these other solutions because they used better-constrained body-wave data.

Distances from the power generating facilities to the rupture plane of the earthquake were computed from the rupture model derived by Campos and others (1996). This rupture model indicates that the earthquake started with a small foreshock located at the hypocenter. This foreshock was about 8.6 seconds in duration and had a low rate of moment release. Then the first major subevent occurred about 30 kilometers to the northeast of the epicenter at a depth of around 46 kilometers. This was followed by a second major subevent about 12 seconds later that was located 48 kilometers to the northeast of the first subevent. The entire source-rupture process was finished in less than 32 seconds. This model indicates that 42% of the moment release occurred during the first subevent and 57% occurred during the second subevent. Campos and others give the following parameters for this rupture model:

Width (down-dip):	50 km
Length:	100 km
Centroid Depth:	46 km (first subevent); 37 km (second subevent)
Strike:	240° (southwest)
Dip:	12.5° to the northwest
Rake:	89° (thrust)
Average Slip:	2.53 m (first subevent); 3.47 m (second subevent)
Seismic Moment:	4.5×10^{27} dyne-cm
Stress Drop:	118 bars

Campos and others show that the above rupture model is consistent with the distribution of aftershocks and provides a very good fit to the coseismic displacements estimated at various locations on Guam from GPS surveys conducted before and after the earthquake by Beavan and others (1994). Campos and others also found that this rupture model was generally consistent with, but provided a better fit to the GPS displacements, than rupture models proposed by Abe (1994) and Tanioka and others (1995), which were based on an inversion of Tsunami waveforms from Japanese tidal gauge stations.

The following distances from the Tanguisson, Yigo, and Dededo facilities to the rupture plane of the Guam earthquake were calculated from the above rupture model and the epicentral coordinates determined by the U.S. Geological Survey (1993):

Site	Epicentral Distance (km)	Azimuth (°)	Energy Center Distance (km)	Rupture Distance (km)
Tanguisson	60.8	0.4	68.5	66.0
Yigo	65.1	8.9	67.3	64.1
Dededo	59.5	3.8	66.1	63.7

In this table, Rupture Distance is the shortest distance between the site and the seismogenic part of the rupture plane of the earthquake, Energy Center Distance is the distance from the site to the energy center of the rupture as defined by Crouse (1991), and Azimuth is the angle between the epicenter and the site measured clockwise from north.

Consistent with the definition of the energy center given by Crouse (1991), the location of this center was placed at the location of the moment centroid of the first, closest subevent. However, rather than use the independently estimated depth of this centroid, the more conservative estimate of 42.4 kilometers, which represents the projection of the subevent onto the modeled rupture plane, was preferred. Distances for the Piti and Cabras facilities were excluded from this analysis for the reasons specified below.

A.4.3 Local Site Conditions

The Earthquake Engineering Research Institute (1995) describes the Piti and Cabras facilities as being underlain by soft soils. The Piti facility is described as being located on loose coral fill underlain by lagoonal and estuarine deposits. The Cabras facility is reported to be founded on loose coral fill over a coral reef. The presence of soft soils and the occurrence of ground failure at the Piti and Cabras Plants indicate that they should be classified as Soil Profile Type S_F (Soft Soil Profile requiring special investigations) based on the soil classifications given in the 1997 *Uniform Building Code* (UBC) (ICBO, 1997). Sites in this soil category require site-specific investigations to determine their dynamic soil-response characteristics. As a result, it is not possible to reliably estimate the ground motion at these facilities without performing a dynamic site-response analysis using site-specific geotechnical information.

There are no reliable site-specific geotechnical information for the Tanguisson, Yigo, and Dededo facilities. Instead, the local site conditions at these facilities were determined from a 1:50,000-scale geology map of Guam (Tracey and others, 1964). According to this map, the Tanguisson facility is underlain by reef facies of the Pliocene and Pleistocene Mariana Limestone. This unit is a massive, generally compact, porous and cavernous white limestone of reef origin. The Yigo site is underlain by detrital facies of the Mariana Limestone. This unit is a friable to well-cemented, coarse-to-fine grained, generally porous and cavernous white detrital limestone, mostly of lagoonal origin. The Dededo facility is underlain by the Miocene and Pliocene Barrigada Limestone. This unit is a massive, well-lithified to friable medium-to-coarse grained white foraminiferal limestone.

As reported by Dames & Moore (1994), various geophysical investigations have been performed to investigate the physical nature and configuration of the volcanic rocks and limestone on the island. Of particular interest are seismic refraction surveys and gravity surveys performed in 1982 by the Guam Environmental Protection Agency. The results of these studies indicate that the seismic velocities in the upper part of the limestone are relatively low. The surface layer of limestone, between 30 and 38 meters thick, has an average compressional-wave velocity of 945 m/s. According to Dames & Moore, this corresponds to an estimated shear-wave velocity of 460 m/s. Below the upper layer of limestone is a second limestone layer with an average compressional-wave velocity of 2,040 m/s and an estimated shear-wave velocity of 915 m/s. The volcanic basement beneath the second limestone layer has an average compressional-wave velocity of about 2,835 m/s.

The shear-wave velocity in the upper limestone layer is within the lower part of the range of shear-wave velocities (360 to 760 m/s) that are used to define Soil Profile Type S_C (Very Dense Soil and Soft Rock) in the 1997 UBC. However, considering that the shear-wave velocities reported by Dames & Moore (1994) represent an average of many measurements, it is possible that some of these sites had shear-wave velocities that fell within the upper part of the range of shear-wave velocities (180 to 360 m/s) that are used to define Soil Profile Type S_D (Stiff Soil Profile). Because of this uncertainty, it can be concluded that the Tanguisson, Yigo, and Dededo sites can be classified as either Soil Profile Types S_D or S_C.

A.4.4 Recommended Response Spectrum

Because of the lack of strong-motion recordings on the island, it was decided to develop a quantitative estimate of ground shaking at the Guam power generating facilities using a selected set of empirical attenuation relationships developed from worldwide strong-motion recordings of subduction earthquakes. These attenuation relationships were developed by Kawashima and others (1984, 1986), Annaka and Nozawa (1988), Crouse (1991), Dames & Moore (1994), Molas and Yamazaki (1995, 1996), and Youngs and others (1997). Each of these attenuation relationships requires a set of specific earthquake parameters in order to use them correctly. Magnitude measures include moment magnitude M_w and Japan Meteorological Agency (JMA) magnitude M_j. Distance measures include epicentral distance, closest distance to the rupture plane, and distance to the energy center of the earthquake. Also required for some relationships are the focal depth, the depth to the closest part of the fault rupture, and the type of subduction event (interplate versus intraslab).

The earthquake parameters used to estimate the ground motions from each of the attenuation relationships are given in the following table.

Parameter	Crouse	Youngs et al.	Kawashima et al.	Annaka & Nozawa	Molas & Yamazaki
Magnitude Measure	7.7 M_w	7.7 M_w	7.6 M_j	7.6 M_j	7.6 M_j
Distance Measure	Distance to Energy Center	Closest Distance to Rupture	Epicentral Distance	Closest Distance to Rupture	Closest Distance to Rupture
Focal Depth (km)	41.5	41.5	—	41.5	41.5
Source Type	—	Interface ($Z_T = 0$)	—	—	—
Component	Average Horizontal	Average Horizontal	Resultant Horizontal	Average Horizontal	Largest Horizontal
Site Conditions	Firm Soil & Rock	Soil & Rock	Firm Soil & Rock	$V_s = 300$ to 600 m/s	Hard Soil & Rock

In the above table, the value of M_w was estimated from the seismic moment of 4.5×10^{27} dyne-cm determined by Campos and others (1996) using the moment-magnitude relationship of Hanks and Kanamori (1979). The value of M_j was estimated from the average of the estimates calculated from the seismic moment versus M_j relationships published by Sato (1979) and Satoh and others (1997) using this same estimate of seismic moment. An estimate of the average horizontal component of ground motion was calculated from the amplitude of the resultant horizontal component and the largest horizontal component by applying the frequency-dependent ratios developed by Ansary and others (1995).

So as not to give undue influence to the attenuation relationships that are based solely on Japanese strong-motion recordings, the three Japanese relationships were given the same total weight as the other attenuation relationships in the calculation of the weighted average ground motion. The estimated average horizontal value of PGA calculated from each of the five attenuation relationships for each generic site condition, along with the weighted average from the five relationships, is summarized in the following table.

Facility	Kawashima et al. (1/9 wgt.)	Annaka & Nozawa (1/9 wgt.)	Crouse; Dames & Moore (1/3 wgt.)	Molas & Yamazaki (1/9 wgt.)	Youngs et al. (1/3 wgt.)	Weighted Average
Tanguisson						
Rock	0.151	0.165	0.127	0.090	0.130	0.130
Firm Soil	0.195	0.165	0.216	0.095	0.208	0.187
Yigo						
Rock	0.143	0.171	0.129	0.093	0.134	0.131
Firm Soil	0.184	0.171	0.219	0.099	0.213	0.190
Dededo						
Rock	0.154	0.173	0.130	0.094	0.135	0.133
Firm Soil	0.198	0.173	0.222	0.100	0.214	0.193

Note that the range of weighted average PGA estimates (0.130*g* to 0.193*g*) is generally consistent with the range of effective accelerations estimated by the Earthquake Engineering Research Institute (1995) from an evaluation of liquefaction effects and damage to bus stops (0.15*g* to 0.25*g*).

Figures A-10 and A-11 show the estimated 5%-damped acceleration response spectra for the Tanguisson facility. Inspection of these figures indicate that the estimated spectral accelerations on rock are lower than those on firm soil at all frequencies. Because of the uncertainty in the classification of the sites into one of the 1997 UBC Soil Profile Types, the lower estimates for rock, which are consistent with Soil Profile Type S_C, were used to conservatively estimate the expected response spectrum at the three facility sites.

Because of the similarity in the estimated ground motions for the three facility sites, the empirical estimates on rock for the Tanguisson site were used as a credible, although somewhat conservative (i.e., lower), estimate of the ground motion at the Tanguisson, Yigo, and Dededo power generating facilities. The mean, 16th-percentile, and 84th-percentile empirical estimates on rock at the three sites are graphically displayed in Figure A-12. The recommended (mean) 5%-damped acceleration response spectrum is shown in Figure A-13. There is insufficient geotechnical information to develop recommended response spectra for the Piti and Cabras facilities.

A.5 Whitewater Hydroelectric Plant (Scenario 3)

The Whitewater Hydroelectric Plant is located near the town of Banning in Riverside County, California. It is located about 4.5 kilometers from the surface projection of the fault rupture plane of the July 8, 1986 local magnitude (M_L) 5.9 North Palm Springs earthquake.

The North Palm Springs earthquake caused limited damage in the Palm Springs region (Stover and Coffman, 1993). It was assigned a maximum intensity of VII on the Modified Mercalli Intensity (MMI) scale. Shaking effects consistent with MMI VII were observed in Palm Springs, North Palm Springs, Banning, the Southern California Edison substation Devers electrical substation, and near the mouth of Whitewater Canyon. In Whitewater Canyon three homes were destroyed when walls were severely cracked, there was some partial collapses, and chimneys fell. Damage at the Devers substation consisted of many broken ceramic columns and as much as 10 inches of movement of transformers resulting from sheared retaining bolts. En echelon fractures formed along the Banning fault for about 9 kilometers on both sides of State Highway 62 north of Palm Springs and in the vicinity of North Palm Springs, the Devers substation, and Whitewater Canyon (Sharp and others, 1986).

A.5.1 Strong-Motion Recordings

There was no strong-motion recording at the Whitewater Plant. There were, however, three ground-level recordings within 10 kilometers of the plant at the Devers substation near the intersection of I-10 and State Highway 62 (SCE Devers, 5.2 kilometers), the Whitewater Trout Farm in Whitewater Canyon (USGS #5072, 7.3 kilometers), and the U.S. Post Office in North Palm Springs (USGS #5070, 8.5 kilometers). All three recordings are located close enough to the Whitewater Plant to have experienced similar levels of ground shaking. However, they are not all located at similar epicentral azimuths and likely did not experience the same source characteristics during the earthquake (see discussion below).

Porcella and others (1986, 1987) give a detailed description of the USGS recordings. Swan and others (1985) and an unpublished letter from the Southern California Edison Company (Tom Kelly, written comm., 1987) give a description of the Devers recording. A summary of this information is provided in the following table.

Parameter	SCE-Devers	USGS #5072	USGS #5070
Structure	Inst. shelter.	1-story bldg.	1-story bldg.
Location	Ground level	Ground level	Ground level
Latitude	33.932°N	33.989°N	33.924°N
Longitude	116.579°W	116.655°W	116.543°W
Peak Ground Acceleration (g)	0.97 (North) 0.72 (East) 0.48 (Up)	0.66 (East) 0.50 (South) 0.44 (Up)	0.70 (S30W) 0.68 (N60W) 0.78 (Up)

The Whitewater Trout Farm and the North Palm Springs recordings were never digitized by the USGS so it is not possible to compute response spectra. The two horizontal components of the 5%-damped acceleration response spectra from the Devers substation (Tom Kelley, written comm., 1987) are shown in Figure A-14.

A.5.2 Earthquake Parameters

Jones and others (1986) and the U.S. Geological Survey (1986) report the following seismological parameters for the North Palm Springs Earthquake:

Date:	July 8, 1986
Time:	9:20:45 Greenwich Mean Time (GMT)
Magnitude:	5.9–6.0 M_L, 6.0 M_S, 5.7–6.0 M_W
Epicenter:	34.000°N, 116.605°W
Depth:	11.3 km
Rupture:	Bilateral or circular; 6–15 km in depth from aftershocks
Size:	16 km long by 9 km wide in plan view from aftershocks
Strike:	300° (northwest) from aftershocks 300° (northwest) from focal mechanism
Dip:	50° to the northeast from aftershocks 45° to the northeast from focal mechanism
Rake:	180° (strike slip)

Using teleseismic and braodband recordings, Pacheco and Nabelek (1988) determined the following rupture model for the earthquake:

Strike:	283° (northwest)
Dip:	41° to the northeast
Centroid Depth:	11.4 km
Source Radius:	5.0 km (entire rupture plane) 2.7 KM (major asperity)
Rake:	147° (reverse-oblique)
Slip:	35 cm (major asperity)
Stress Drop:	34 bars (average over rupture plane) 151 bars (major asperity)
Seismic Moment:	9.7×10^{24} dyne-cm (average over rupture plane) 6.8×10^{24} dyne-cm (major asperity)

The teleseismically determined seismic moment of 9.7×10^{24} dyne-cm is consistent with a moment magnitude (M_W) of 6.0 based on the moment-magnitude relationship of Hanks and Kanamori (1979).

Similar rupture parameters were found by Hartzell (1989) from separate inversions of teleseismic recordings, strong-motion recordings (both linear and nonlinear inversion), and empirical Greens functions. The largest difference in the Hartzell results was in the seismic moment ($1.6–1.8 \times 10^{24}$ dyne-cm), which corresponds to a moment magnitude of 6.1. Pacheco and Nabelek explain the difference between their mechanism (reverse-oblique) and that of Jones and others (pure strike slip) as a difference between the mechanism of the entire rupture process as compared to that of only the first motion. Hartzell also found predominantly reverse-oblique slip in his inversions.

The following distances from the recording and Whitewater sites to the rupture plane of the North Palm Springs earthquake were calculated from the epicentral coordinates, the aftershock distribution determined by Jones and others (1986), and the slip distribution on the rupture plane determined by Hartzell (1989):

Site	Epicentral Distance (km)	Azimuth (°)	Surface Distance (km)	Rupture Distance (km)
Whitewater HP	8.8	198	4.6	9.4
SCE-Devers	7.9	162	1.3	7.1
USGS #5072	4.8	255	0	7.9
USGS #5070	10.2	146	3.1	7.7

In this table, Rupture Distance is the shortest distance between the site and the seismogenic part of the rupture plane of the earthquake, Energy Center Distance is the distance from the site to the energy center of the rupture as defined by Crouse (1991), and Azimuth is the angle between the epicenter and the site measured clockwise from north.

A.5.3 Local Site Conditions

Both the Whitewater Hydroelectric Plant and the Devers and North Palm Springs recording sites are located at the northern end of the Coachella Valley. The Whitewater Plant is located near the mouth of Whitewater Canyon. The Whitewater Trout Farm is located further up Whitewater Canyon. There is no reliable site-specific geotechnical information for the Whitewater Plant or the three recording sites. However, a geologic map of the area (Proctor, 1968) indicates that the Whitewater Plant and the Devers and North Palm Springs recording sites are covered with a thin veneer of wind-blown sand. Underlying the sand is the Pleistocene Cabezon Fanglomerate Formation, which is described as a sandy, poorly sorted conglomerate. The thickness of the Cabezon Fanglomerate is estimated to be 1000 feet. Underlying the Cabezon Fanglomerate is the Plio-Pleistocene Painted Hill Formation that unconformably overlies crystalline basement rock. The Painted Hill formation is a sandy, well-rounded conglomerate that is estimated to be over 3,400 feet thick. The total thickness of the sedimentary deposits at the Whitewater Trout Farm recording site is only a few hundred feet.

The average shear-wave velocity in the top 30 meters of the Pleistocene Fanglomerate that underlies the Whitewater Plant and the Devers and North Palm Springs recording sites was estimated from shear-wave velocity characteristics determined for different geologic units in California by Wills and Silva (1998). According to this study, the Pleistocene deposit is expected to fall near the boundary of Soil Profile Types S_D (Stiff Soil Profile) and S_C (Soft Rock and Very Dense Soil) based on the soil classifications given in the 1997 *Uniform Building Code* (UBC) (ICBO, 1997). As measured from the middle of the velocity ranges defining these two Soil Profile Types, this boundary has a shear-wave velocity in the top 30 meters that ranges between 270 and 560 m/s. Based on the above information, it can be concluded that the Plant and two recording sites have similar soil-amplification characteristics. The different lithology of the Whitewater Trout Farm site would suggest that it does not have similar soil-amplification characteristics as the other three sites.

A.5.4 Recommended Response Spectra

None of the strong-motion recordings are close enough to the Whitewater Hydroelectric Plant to be chosen unequivocally as the sole representation of the expected ground motion at the Plant without further consideration. However, both the Devers recording and the Whitewater Plant, even though they are located about 5 kilometers apart, have many attributes in common that suggest that they were probably subjected to similar ground motion during the earthquake. First, they are both located a few kilometers north of the surface trace of the Banning fault, directly up-dip from the major asperity identified from the rupture models. Therefore, they are both likely to have experienced similar directivity effects (e.g., Somerville and others, 1997). Second, they are both located adjacent to that part of the Banning fault with mapped trace-fractures (Sharp and others, 1986) and that might have had some shallow slip (Hartzell, 1989). The trace-fractures and shallow slip could have been caused by the large dynamic stresses that were generated by the source directivity and relatively large stress drop associated with the major asperity. Lastly, they are located on similar types of soils and have similar depths to the top of basement rock.

In contrast, the North Palm Springs recording is located about 3 kilometers southeast of the rupture plane and 8.5 kilometers from the Whiterwater Plant. Nonetheless, this recording was also likely to have experienced directivity effects, although probably not as great as the other two sites, because of its favorable location with respect to the surface trace of the Banning fault. It is also located on similar site conditions and has a similar depth to the top of basement rock. The Whitewater Trout Farm is located directly over the surface projection of the inferred rupture plane, but it has a relatively large angle with respect to this plane. Therefore, it is not likely to have experienced the same strong directivity effects as the Devers substation or to a lesser extent the North Palm Springs Post Office. Furthermore, it is located much further up Whitewater Canyon where the depth to basement rock is relatively shallow and the surficial site conditions are different.

Based on the above discussion, the Devers recording is likely to have the most representative ground motion of the three closest recordings of that which was likely to have been experienced at the Whitewater Plant. However, its relatively large distance from the plant (5 kilometers) and its somewhat closer distance to the rupture plane (7.1 versus 9.4 kilometers) makes it difficult to justify using this recording without some adjustment. It is clear that the Whitewater Trout Farm is not a suitable candidate. However, based on the above discussion, the North Palm Springs recording is a reasonable candidate. However, its somewhat larger distance from the rupture plane, its less favorable orientation with respect to the rupture plane, and its location within a 1-story building likely makes it a conservative (i.e. lower) estimate of the ground motion at the Whitewater plant.

Based on the above discussion, it can be concluded that a credible, although somewhat conservative (i.e., lower), estimate of the ground motion at the Whitewater Hydroelectric Plant can be obtained by taking an average of the Devers and North Palm Springs recordings. Since there are no digitized data available for the North Palm Springs recording, the recommended spectrum was estimated by scaling the Devers spectrum to the average of the two horizontal components of the peak ground acceleration from the Devers and the North Palm Springs recordings. The resulting recommended spectrum is given in Figure A-15.

Boore (1997) also provided high-frequency estimates of ground motion at the Whitewater Hydroelectric Plant. However, he used the Whitewater Trout Farm recording in addition to the Devers substation recording to derive his estimates. As compared to the North Palm Springs recording, the Whitewater Trout Farm recording is believed to be less suitable than the North Palm Springs recording for estimating the ground motion at the Whitewater Plant because it is located at a significantly different epicentral azimuth (255° versus 146°; the Plant has an azimuth of 198°), it is much less favorably oriented with respect to source directivity effects (i.e., Somerville and others, 1997), and it has a much shallower depth to basement rock.

A.6 IBM Santa Teresa Facility HVAC (Scenario 1)

The IBM Santa Teresa Computer Facility is located in the city of San Jose in Santa Clara County, California. It is located about 12 kilometers from the surface projection of the rupture plane of the April 24, 1984 moment-magnitude (M_w) 6.2 Morgan Hill earthquake.

The Morgan Hill earthquake caused limited damage in the Morgan Hill region (Stover, 1984). It was assigned a maximum intensity of VII on the Modified Mercalli Intensity (MMI) scale. Shaking effects consistent with MMI VII were observed in Morgan Hill and southern San Jose. The Santa Teresa Facility falls within the region of MMI VII effects.

A.6.1 Strong-Motion Recordings

There were four strong-motion recordings at the Santa Teresa Facility (Kinemetrics, 1984). Unfortunately, the only free-field instrument at the site had a malfunction and did not produce a reliable recording. Although many publications have quoted peak accelerations from this instrument, they should be considered unreliable. The most relevant recording was from an accelerograph in the 1-story concrete HVAC building, which recorded peak ground accelerations of 0.33*g* and 0.22*g* in the East and North directions, respectively (Kinemetrics, 1984; Swan and others, 1985). The vertical channel malfunctioned so no vertical record was obtained. The 5%-damped acceleration response spectra for the two horizontal components are shown in Figure A-16. These spectra were calculated by K. Campbell at 15 periods ranging from 0.04 to 4.0 seconds from accelerograms that he had processed while at the USGS. The original accelerograms were lost, so these are the only spectra that are currently available.

A.6.2 Earthquake Parameters

Eaton (1987) and Crockerham and Eaton (1987) report the following seismological parameters for the Morgan Hill earthquake:

Date:	April 24, 1984
Time:	21:15:19 Greenwich Mean Time (GMT)
Magnitude:	6.2 M_L
Epicenter:	37.309°N, 121.679°W
Depth:	8.7 km
Strike:	327° (northwest)
Dip:	84° to the northeast
Rake:	180° (strike slip)
Rupture Width:	7 km (from aftershock distribution)
Rupture Length:	25 km (from aftershock distribution

Using strong-motion and teleseismic recordings, Hartzell and Heaton (1986) determined the following rupture parameters for the earthquake:

Average Slip:	1.0 m
Seismic Moment:	2.1×10^{25} dyne-cm

The seismic moment of 2.1×10^{25} dyne-cm is consistent with a moment magnitude (M_w) of 6.2 based on the moment-magnitude relationship of Hanks and Kanamori (1979). Similar estimates of seismic moment were obtained by numerous other investigators.

The following distances from the Santa Teresa Facility to the rupture plane of the Morgan Hill earthquake were calculated from the aftershock distribution of Crockerham and Eaton:

Site	Epicentral Distance (km)	Azimuth (°)	Surface Distance (km)	Rupture Distance (km)
Santa Teresa	13.9	206	11.6	12.8

In this table, Rupture Distance is the shortest distance between the site and the seismogenic part of the rupture plane of the earthquake, Surface Distance is the shortest distance between the site and the surface projection of this rupture plane, and Azimuth is the angle between the epicenter and the site measured clockwise from north.

A.6.3 Local Site Conditions

There is no reliable site-specific geotechnical information for the IBM Santa Teresa Facility. However, a geologic map of the area (Helley and Brabb, 1971) indicates that the Facility is located on Pleistocene alluvial fan deposits. There is evidence of three periods of alluvial fan development in the southern Santa Clara Valley. The Pleistocene alluvial fans form a broad apron above the younger fans, extending to the base of the bedrock uplands that form the margins of the Santa Clara Valley. These sediments are coarser grained than those comprising the younger fans and usually display distinctive strongly developed soil profiles characterized by fragipan (hard, brittle loam) in the subsurface. This fragipan is very hard and impermeable and permits little surface water infiltration. Standard Penetration Test (SPT) resistance for the older fan deposits range from 11 ± 9 blows/ft above the fragipan to 88 ± 23 below the fragipan (Helley and Brabb, 1971). Bedrock is known to outcrop about 200 meters northwest of the site, which suggests that the Pleistocene alluvial fan deposits are relatively thin and that bedrock occurs at a relatively shallow depth beneath the Facility.

Because of the presence of the fragipan, it is difficult to classify the soil conditions at the Facility. Fortunately, this is not important since there is a recording on site. Nonetheless, the site is likely to be classified as Soil Profile Type S_C (Soft Rock and Very Dense Soil) based on the soil classification given in the 1997 *Uniform Building Code* (UBC) (ICBO, 1997). This Soil Profile Type has a shear-wave velocity in the top 30 meters that ranges between 360 and 760 m/s.

A.6.4 Recommended Response Spectra

The recording obtained in the 1-story HVAC building is the recommended recording for the Santa Teresa Facility. However, the building is partially buried on two sides where it is embedded into a soil berm, and its massive concrete slab and walls are likely to have attenuated high-frequency ground motion due to scattering and wave-passage effects. Therefore, it cannot be considered a free-field recording. However, it is the most reliable estimate of the ground motion to which the HVAC equipment was subjected within the building. It is, however, a conservative (i.e., lower) estimate of the free-field ground motion that occurred in the vicinity of the HVAC building. The recommended 5%-damped acceleration response spectrum is shown in Figure A-17.

A.7 U.C. Santa Cruz Central Campus (Scenario 2)

There are four buildings of interest within the U.C. Santa Cruz (UCSC) central campus area. These are the Applied Sciences Building, the Earth Sciences Building, Thimann Labs, and Sinsheimer Labs. The UCSC campus is located in the city of Santa Cruz in Santa Cruz County, California. It is situated about 20 kilometers southwest of the surface projection of the rupture plane of the October 17, 1989 moment-magnitude (M_w) 7.0 Loma Prieta earthquake.

The Loma Prieta earthquake caused widespread damage throughout the Santa Cruz and San Francisco regions (Plafker and Galloway, 1989; Stover and others, 1990). It was assigned an epicentral intensity of VIII on the Modified Mercalli Intensity (MMI) scale (MMI). However, an even higher intensity of MMI IX was assigned to San Francisco's Marina District, where widespread liquefaction occurred, and to four areas located on soft soils that experienced significant damage and collapse of elevated reinforced-concrete viaducts. These areas are the Nimitz Freeway viaduct (Interstate 880, Cyprus Section) in Oakland; and the Embarcadero, Highway 101, and Interstate 280 viaducts in San Francisco. Shaking effects consistent with MMI VIII were observed in Hollister, Los Gatos, parts of Oakland, Santa Cruz, Scotts Valley, and Watsonville, as well as in many other towns and communities in the epicentral region. Shaking intensity VII effects were observed along the west and east margins of San Francisco Bay as far north as San Francisco and Oakland.

A.7.1 Strong-Motion Recordings

There was a strong-motion recording on the first floor of the Applied Sciences Building (UCSC Station UCSC). The building is a three-story cast-in-place concrete structure with a basement (McNally and others, 1996). There was a second recording that was located in the one-story UCSC Lick Observatory Electrical Lab near the parking lot of the Applied Sciences Building (CSMIP #58135). The four buildings are located approximately 200 to 400 meters from the Lick Observatory recording and even closer to the Applied Sciences Building recording.

Shakal and others (1989), CSMIP (1991), and McNally and others (1996) give a detailed description of the two recordings. A summary of this information is provided in the following table. The peak accelerations for the Applied Sciences Building recording were obtained from uncorrected accelerograms provided by UCSC.

Parameter	CSMIP #58135	UCSC
Structure	1-story bldg.	3-story bldg.
Location	Ground level	First floor*
Latitude	37.001°N	37.000°N
Longitude	122.060°W	122.062°W
PGA (g)	0.47 (North) 0.44 (East) 0.40 (Up)	0.31 (North) 0.42 (East) 0.22 (Up)

*One floor above the basement

The reduced values of peak acceleration in the Applied Sciences Building are consistent with the effects of soil-structure interaction. The two horizontal components of the 5%-damped acceleration response spectra are graphically displayed in Figures A-18 and A-19.

A.7.2 Earthquake Parameters

Earthquake parameters from seismological and wave-modeling studies for the Loma Prieta earthquake are provided in the *Bulletin of the Seismological Society of America* (1991), which is summarized by Hanks and Krawinkler (1991), and in U.S. Geological Survey (1996), which is summarized by Spudich (1996). Spudich (1996) and Eberhart-Phillips and others (1990) report the following seismological parameters for the earthquake:

Date:	October 18, 1989
Time:	4:15.2 Greenwich Mean Time (GMT)
Magnitude:	7.0 M_w
Epicenter:	37.036°N, 121.883°W
Depth:	19 km
Stress Drop:	50 bar (average)
Strike:	130° (southeast)
Dip:	70° to the southwest
Rake:	130° (reverse-oblique)

Similar source mechanisms were obtained by many other seismologists (e.g., *Geophysical Research Letters*, vol. 17, no. 9, 1990; *Bulletin of the Seismological Society of America* (1991), U.S. Geological Survey (1996).

Using strong-motion and broadband teleseismic recordings, Wald and others (1996) determined the following rupture model for the earthquake:

Width (down-dip):	20 km
Length:	40 km
Depth to Top:	4–6 km
Strike:	128° (southeast)
Dip:	70° to the southwest
Rake:	142° (average; reverse-oblique)
Average Slip:	2.5 m (northwest section) 1.8 m (southeast section)
Seismic Moment:	2.2×10^{26} dyne-cm (northwest section) 0.8×10^{26} dyne-cm (southeast section) 3.0×10^{26} dyne-cm (total)
Stress Drop:	218 bars (northwest section) 136 bars (southeast section

The total seismic moment of 3.0×10^{26} dyne-cm is consistent with a moment magnitude (M_w) of 7.0 based on the moment-magnitude relationship of Hanks and Kanamori (1979). Hanks and Krawinkler (1991) recommended the same "consensus value" for moment magnitude. The fault rupture model is consistent with bilateral rupture with the largest slip towards the northwest. It is also consistent with the aftershock distribution determined by Dietz and Ellsworth (1990).

The following distances from the recording and UCSC building sites to the rupture plane of the Loma Prieta earthquake were calculated from the above rupture model, the epicentral coordinates reported by Spudich (1996), and the aftershock distribution determined by Plafker and Galloway (1989) and Dietz and Ellsworth (1990):

Site	Epicentral Distance (km)	Azimuth (°)	Surface Distance (km)	Rupture Distance (km)
Applied Science	16.4	256	20.1	13.7
Sinsheimer Lab	16.5	256	20.2	13.8
Thimann Lab	16.5	255	20.3	13.9
Natural Science	16.3	255	20.2	13.8
CSMIP #58135	16.2	256	20.0	13.5

In this table, Rupture Distance is the shortest distance between the site and the seismogenic part of the rupture plane of the earthquake, Surface Distance is the shortest distance between the site and the surface projection of this rupture plane, and Azimuth is the angle between the epicenter and the site measured clockwise from north.

A.7.3 Local Site Conditions

There is no reliable site-specific geotechnical data available for the UCSC or recording sites. However, a geologic map of the area (Clark, 1981) indicates that all of the sites are underlain by high-grade metasedimentary rock. Originally composed of sandstone, shale, and carbonate beds of Paleozoic or Mesozoic age, this rock was metamorphosed to schist and quartzite by a regional intrusion of granitic plutons that are 70 to 90 million years old. The metasedimentary rock can be considered crystalline basement rock.

Because all of the sites are underlain by the same geologic unit, it is not necessary that this unit be classified. Nonetheless, based on the relationship between shear-wave velocity and different geologic units in California derived by Wills and Silva (1998), it is likely that the sites would fall in the upper part of Soil Profile Type S_C (Very Dense Soil and Soft Rock) based on the soil classification given in the 1997 *Uniform Building Code* (UBC) (ICBO, 1997). This Soil Profile Type has a shear-wave velocity in the top 30 meters that ranges between 360 and 760 m/s.

A.7.4 Recommended Response Spectra

Based on the proximity of the UCSC buildings to the Lick Observatory recording (200–400 meters), the similar distance from all four sites to the rupture plane of the Loma Prieta earthquake (13.5 to 13.9 kilometers), the similar epicentral azimuths of all of the sites (255° to 256°), and the similar soil-amplification characteristics at all of the sites, it can be concluded that the Lick Observatory recording is a credible, although somewhat conservative (i.e., lower), estimate of the free-field ground motion at the UCSC central campus sites. The conservatism comes from the fact that the Lick Observatory recording was obtained in a small 1-story building that might have reduced the high-frequency components of the ground motion somewhat due to scattering and wave-propagation effects.

The recording on the first floor of the Applied Sciences Building is not believed to be a credible estimate of the free-field ground motion because of the size and embedment of the structure and the fact that the recording is not located at foundation level. This is seen in Figure A-20, where the Applied Sciences recording is found to be less than the Lick Observatory recording at frequencies between 2 and 5 Hz. The recommended (Lick Observatory) 5%-damped acceleration response spectrum is shown in Figure A-21. The recommended response spectrum is identical to that recommended by Boore (1997) for the UCSC Cogeneration Plant.

A.8 Santa Cruz Water Treatment Plant (Scenario 2)

The Santa Cruz Water Treatment Plant is located in the city of Santa Cruz in Santa Cruz County, California. It is located 18.5 kilometers southwest of the surface projection of the rupture plane of the October 17, 1989 moment-magnitude (M_w) 7.0 Loma Prieta earthquake.

The Loma Prieta earthquake caused widespread damage throughout the Santa Cruz and San Francisco regions (Plafker and Galloway, 1989; Stover and others, 1990). It was assigned an epicentral intensity of VIII on the Modified Mercalli Intensity (MMI) scale (MMI). However, an even higher intensity of MMI IX was assigned to San Francisco's Marina District, where widespread liquefaction occurred, and to four areas located on soft soils that experienced significant damage and collapse of elevated reinforced-concrete viaducts. These areas are the Nimitz Freeway viaduct (Interstate 880, Cyprus Section) in Oakland; and the Embarcadero, Highway 101, and Interstate 280 viaducts in San Francisco. Shaking effects consistent with MMI VIII were observed in Hollister, Los Gatos, parts of Oakland, Santa Cruz, Scotts Valley, and Watsonville, as well as in many other towns and communities in the epicentral region. Shaking intensity VII effects were observed along the west and east margins of San Francisco Bay as far north as San Francisco and Oakland.

A.8.1 Strong-Motion Recordings

There was no strong-motion recording at the Water Treatment Plant. The closest recording to the facility was 2.4 kilometers away at the Lick Observatory Electrical Lab. (CSMIP Station #58135). The geographic coordinates of the recording site are 37.001°N latitude and 122.060°W longitude. The accelerograph, which is located at ground level in a small one-story building, recorded peak ground accelerations of 0.47*g*, 0.44*g*, and 0.40*g* in the North, East, and Vertical directions, respectively (Shakal and others, 1989). The 5%-damped acceleration response spectra for the two horizontal components (CSMIP, 1991) are shown in Figure A-22.

A.8.2 Earthquake Parameters

Earthquake parameters from seismological and wave-modeling studies for the Loma Prieta earthquake are provided in the *Bulletin of the Seismological Society of America* (1991), which is summarized by Hanks and Krawinkler (1991), and in U.S. Geological Survey (1996), which is summarized by Spudich (1996). Spudich (1996) and Eberhart-Phillips and others (1990) report the following seismological parameters for the earthquake:

Date:	October 18, 1989
Time:	4:15.2 Greenwich Mean Time (GMT)

Magnitude:	7.0 M_w
Epicenter:	37.036°N, 121.883°W
Depth:	19 km
Stress Drop:	50 bar (average)
Strike:	130° (southeast)
Dip:	70° to the southwest
Rake:	130° (reverse-oblique)

Similar source mechanisms were obtained by many other seismologists (e.g., *Geophysical Research Letters*, vol. 17, no. 9, 1990; *Bulletin of the Seismological Society of America* (1991), U.S. Geological Survey (1996).

Using strong-motion and broadband teleseismic recordings, Wald and others (1996) determined the following rupture model for the earthquake:

Width (down-dip):	20 km
Length:	40 km
Depth to Top:	4–6 km
Strike:	128° (southeast)
Dip:	70° to the southwest
Rake:	142° (average; reverse-oblique)
Average Slip:	2.5 m (northwest section) 1.8 m (southeast section)
Seismic Moment:	2.2×10^{26} dyne-cm (northwest section) 0.8×10^{26} dyne-cm (southeast section) 3.0×10^{26} dyne-cm (total)
Stress Drop:	218 bars (northwest section) 136 bars (southeast section

The total seismic moment of 3.0×10^{26} dyne-cm is consistent with a moment magnitude (M_w) of 7.0 based on the moment-magnitude relationship of Hanks and Kanamori (1979). Hanks and Krawinkler (1991) recommended the same "consensus value" for moment magnitude. The fault rupture model is consistent with bilateral rupture with the largest slip towards the northwest. It is also consistent with the aftershock distribution determined by Dietz and Ellsworth (1990).

The following distances from the recording and Plant sites to the rupture plane of the Loma Prieta earthquake were calculated from the above rupture model, the epicentral coordinates reported by Spudich (1996), and the aftershock distribution determined by Plafker and Galloway (1989) and Dietz and Ellsworth (1990):

Site	Epicentral Distance (km)	Azimuth (°)	Surface Distance (km)	Rupture Distance (km)
Santa Cruz WTP	16.4	256	20.1	13.7
CSMIP #58135	13.9	254	18.5	11.9

In this table, Rupture Distance is the shortest distance between the site and the seismogenic part of the rupture plane of the earthquake, Surface Distance is the shortest distance between the site and the surface projection of this rupture plane, and Azimuth is the angle between the epicenter and the site measured clockwise from north.

A.8.3 Local Site Conditions

There is no reliable site-specific geotechnical data available for the Water Treatment Plant or Lick Observatory sites. However, a geologic map of the area (Clark, 1981) indicates that the Lick Observatory site is underlain by high-grade metasedimentary rock. Originally composed of sandstone, shale, and carbonate beds of Paleozoic or Mesozoic age, this rock was metamorphosed to schist and quartzite by a regional intrusion of granitic plutons that are 70 to 90 million years old. The metasedimentary rock can be considered crystalline basement rock.

The Water Treatment Plant is underlain by a thin layer of a Tertiary sedimentary unit known as the Santa Margarita Sandstone that lies above the same metasedimentary rock unit that underlies the Lick Observatory site. The Santa Margarita Sandstone is a thickly bedded, well-sorted, uncemented arcosic sand that was deposited in a shallow marine environment. It reaches its maximum thickness of 130 meters approximately 11 kilometers north of the Water Treatment Plant. It thins southward towards the Plant. In the vicinity of the Plant, the Santa Margarita Sandstone is estimated to be less than 50 meters thick and probably much thinner (see below).

According to the geologic map, the three western-most circular treatment ponds of the Plant are founded directly on the metasedimentary rock unit. The buildings and the southern-most circular treatment pond appear to be founded on the Santa Margarita Sandstone unit. Since all of the structures are located within close proximity of each other and the Santa Margarita Sandstone is deposited directly on the metasedimentary rock unit, the Santa Margarita Sandstone is likely to be very thin at this location. In fact, it is possible that the structures that appear to be located on this unit could actually be founded directly on the metasedimentary rock if they are embedded deeply enough. Since the Margarita Sandstone is uncemented, this is a likely scenario in order to have provided a firm foundation for the heavier structures.

Based on the relationship between shear-wave velocity and different geologic units in California derived by Wills and Silva (1998), it is likely that those sites underlain by metasedimentary rock would fall in the upper part of Soil Profile Type S_C (Very Dense Soil and Soft Rock) based on the soil classification given in the 1997 *Uniform Building Code* (UBC) (ICBO, 1997). This Soil Profile Type has a shear-wave velocity in the top 30 meters that ranges between 360 and 760 m/s. Because of the uncemented and possibly unconsolidated nature of the Santa Margarita Sandstone, it is likely that those sites, if any, that are founded on this unit would fall within the upper part of Soil Profile Type S_D (Stiff Soil Profile). This Soil Profile Type has a shear-wave velocity that ranges between 180 and 360 m/s.

A.8.4 Recommended Response Spectra

The Santa Cruz Water Treatment Plant, being 11.9 kilometers from the rupture plane of the Loma Prieta earthquake, is about 2 kilometers closer to this plane than the Lick Observatory recording (13.7 kilometers). However the azimuths from the epicenter of the earthquake are virtually identical (256° and 254°) for these two sites, so the kinematic and dynamic fault rupture characteristics were the same. Therefore, based on seismological characteristics alone, the Lick Observatory recording is expected to have generally similar, although somewhat conservative (i.e., lower), ground motions as the Plant.

It is possible based on the site geology that the Plant structures are founded on a thin deposit of uncemented Tertiary sandstone, whereas the recording site is founded on much harder metasedimentary rock. However, it is more likely that these structures are founded directly on the underlying metasedimentary rock. If this is the case, then the Plant site will have similar soil-response amplification effects as the recording site. If not, then it is not clear whether the high-frequency site-response characteristics would lead to lower or higher ground motion at those Plant facilities that are located on the sandstone. If the sandstone were consolidated enough, it might amplify ground motion at all frequencies of interest. If not, then it could attenuate the high-frequency components of ground motion.

Based on the above discussion, the Lick Observatory recording is believed to be a credible, although somewhat conservative (i.e., lower), estimate of the ground motion at the Santa Cruz Water Treatment Plant from the Loma Prieta earthquake for those structures that are founded on metasedimentary rock. For these sites, the recommended 5%-damped acceleration response spectrum is shown in Figure A-23. For those structures (if any) that are located on the Santa Margarita Sandstone, no response spectrum is recommended at this time.

Boore (1997) also provided high-frequency estimates of ground motion for the Water Treatment Plant. However, he used the UCSC Branciforte recording (UCSC Station BRAN; McNally and others, 1996) in Scotts Valley in addition to the Lick Observatory recording to derive his estimates. As compared to the Lick Observatory recording, the Branciforte recording is located further from the Plant (6.7 versus 2.4 kilometers), it is located significantly closer to the surface projection of the rupture plane (5.3 versus 20.0 kilometers), and it is located at a different epicentral azimuth (278° versus 256°). The much closer distance to the surface projection of the rupture plane is significant, because it indicates that the recording is located at a shallower angle with respect to the rupture plane and, therefore, was subjected to reduced radiation-pattern effects. However, this angle is still large enough that there is no expected increase in ground motion as a result of source directivity. The reason that Boore used the Branciforte recording is probably because of its more similar geologic conditions to the Plant site. All things considered, the Lick Observatory recording is believed to be a better representation of the ground motion expected at the Water Treatment Plant for those structures that are located on metasedimentary rock as long as some conservatism in the estimated ground motion is acceptable.

A.9 Calpine Gilroy Cogeneration Plant (Scenario 2)

The Calpine Gilroy Cogeneration Plant is located in the city of Gilroy in Santa Clara County, California. It is located 14 kilometers east of the surface projection of the rupture plane of the October 17, 1989 moment-magnitude (M_w) 7.0 Loma Prieta earthquake.

The Loma Prieta earthquake caused widespread damage throughout the Santa Cruz and San Francisco regions (Plafker and Galloway, 1989; Stover and others, 1990). It was assigned an epicentral intensity of VIII on the Modified Mercalli Intensity (MMI) scale (MMI). However, an even higher intensity of MMI IX was assigned to San Francisco's Marina District, where widespread liquefaction occurred, and to four areas located on soft soils that experienced significant damage and collapse of elevated reinforced-concrete viaducts. These areas are the Nimitz Freeway viaduct (Interstate 880, Cyprus Section) in Oakland; and the Embarcadero, Highway 101, and Interstate 280 viaducts in San Francisco. Shaking effects consistent with MMI VIII were observed in Hollister, Los Gatos, parts of Oakland, Santa Cruz, Scotts Valley, and Watsonville, as well as in many other towns and communities in the epicentral region. Shaking intensity VII effects were observed along the west and east margins of San Francisco Bay as far north as San Francisco and Oakland. The Calpine Plant falls within this latter region.

A.9.1 Strong-Motion Recordings

There was no strong-motion recording at the Calpine Plant. There were, however, ten ground-level recordings within 10 kilometers of the Plant. The closest two recordings were located at the San Ysidro School in Gilroy (CSMIP Station #57382, 1.2 kilometers) and the Gilroy Sewage Treatment Plant (CSMIP Station #47381, 1.6 kilometers). Both recording sites are located close enough to the Calpine Plant to have experienced the same level of ground shaking and earthquake source effects. The other six recordings are not considered to be representative of the ground shaking at the Calpine Plant for the following reasons. They were either too far from the Plant (greater than 8 kilometers), they were founded on significantly different geological deposits, or they were located along the margins of the valley on significantly shallower sediments.

Shakal and others (1989) and CSMIP (1991) give a detailed description of the two selected recordings. A summary of this information is provided in the following table.

Parameter	CSMIP #57382	CSMIP #47381
Structure	1-story bldg.	Inst. shelter.
Location	Ground level	Ground level
Latitude	37.001°N	36.987°N
Longitude	121.521°W	121.536°W
PGA (g)	0.42 (North) 0.22 (East) 0.17 (Up)	0.55 (North) 0.37 (East) 0.37 (Up)

The two horizontal components of the 5%-damped acceleration response spectra of the two selected recordings (CSMIP, 1991) are shown in Figures A-24 and A-25.

A.9.2 Earthquake Parameters

Earthquake parameters from seismological and wave-modeling studies for the Loma Prieta earthquake are provided in the *Bulletin of the Seismological Society of America* (1991), which is summarized by Hanks and Krawinkler (1991), and in U.S. Geological Survey (1996), which is summarized by Spudich (1996). Spudich (1996) and Eberhart-Phillips and others (1990) report the following seismological parameters for the earthquake:

Date:	October 18, 1989
Time:	4:15.2 Greenwich Mean Time (GMT)
Magnitude:	7.0 M_w
Epicenter:	37.036°N, 121.883°W
Depth:	19 km
Stress Drop:	50 bar (average)
Strike:	130° (southeast)
Dip:	70° to the southwest
Rake:	130° (reverse-oblique)

Similar source mechanisms were obtained by many other seismologists (e.g., *Geophysical Research Letters*, vol. 17, no. 9, 1990; *Bulletin of the Seismological Society of America* (1991), U.S. Geological Survey (1996).

Using strong-motion and broadband teleseismic recordings, Wald and others (1996) determined the following rupture model for the earthquake:

Width (down-dip):	20 km
Length:	40 km
Depth to Top:	4–6 km
Strike:	128° (southeast)
Dip:	70° to the southwest
Rake:	142° (average; reverse-oblique)
Average Slip:	2.5 m (northwest section) 1.8 m (southeast section)
Seismic Moment:	2.2×10^{26} dyne-cm (northwest section) 0.8×10^{26} dyne-cm (southeast section) 3.0×10^{26} dyne-cm (total)
Stress Drop:	218 bars (northwest section) 136 bars (southeast section

The total seismic moment of 3.0×10^{26} dyne-cm is consistent with a moment magnitude (M_w) of 7.0 based on the moment-magnitude relationship of Hanks and Kanamori (1979). Hanks and Krawinkler (1991) recommended the same "consensus value" for moment magnitude. The fault rupture model is consistent with bilateral rupture with the largest slip towards the northwest. It is also consistent with the aftershock distribution determined by Dietz and Ellsworth (1990).

The following distances from the recording and Plant sites to the rupture plane of the Loma Prieta earthquake were calculated from the above rupture model, the epicentral coordinates reported by Spudich (1996), and the aftershock distribution determined by Plafker and Galloway (1989) and Dietz and Ellsworth (1990):

Site	Epicentral Distance (km)	Azimuth (°)	Surface Distance (km)	Rupture Distance (km)
Calpine Cogen	31.3	97	12.7	13.5
CSMIP #57382	32.5	97	13.8	14.5
CSMIP #47381	31.4	100	12.2	13.0

In this table, Rupture Distance is the shortest distance between the site and the seismogenic part of the rupture plane of the earthquake, Surface Distance is the shortest distance between the site and the surface projection of this rupture plane, and Azimuth is the angle between the epicenter and the site measured clockwise from north.

A.9.3 Local Site Conditions

Both the Calpine Plant and the selected recording sites are located in the center of the southern Santa Clara Valley. At this point, the valley floor is drained by Llagas Creek and the sediments in the valley are directly related to the depositional processes of this creek. Helley and Nakata (1991) characterize these valley floor deposits as stream channel, levee, flood plain, and alluvial fan deposits, all of Holocene age.

There is no site-specific geotechnical data for either the Plant or recording sites. However, Fumal and others (1984) drilled boreholes at six strong-motion sites in the Gilroy area to determine shear-wave velocity profiles. A 30-meter borehole at the San Ysidro School, located 1.2 km east of the Calpine Plant, indicated that this site was underlain by Holocene flood basin deposits (Helley and Nakata, 1991) to a depth of 9 meters that has a shear-wave velocity of 145 m/s overlying mostly fine-grained Pleistocene alluvium to a depth greater than 30 meters that has a shear-wave velocity of 285 m/s. A 60-meter borehole at the Gilroy Sewage Treatment Plant, located 1.6 kilometers south of the Calpine Plant, indicated that this site was underlain by Holocene levee deposits (Helley and others, 1984) to a depth of 6 meters that has a shear-wave velocity of 165 m/s overlying Pleistocene alluvium to a depth greater than 60 meters that has a shear-wave velocity that ranges from 255 to 625 m/s. The higher velocities are associated with deposits greater than 30 meters deep.

A geologic map of the area (Helley and Nakata, 1991) indicates that the Calpine site is founded on Holocene levee deposits. Since this site is located between the San Ysidro School and the Sewage Treatment Plant and resides on the same surficial deposits, it is likely that the same subsurface site conditions that exist at these two recording sites are present at the Calpine Plant. Based on the above information, both the Calpine Plant and the recording sites can be classified as Soil Profile Type S_D (Stiff Soil Profile) based on the soil classification given in the 1997 *Uniform Building Code* (UBC) (ICBO, 1997). This Soil Profile Type has a shear-wave velocity in the top 30 meters that ranges between 180 and 360 m/s. Based on the above information, it can be concluded that both the Plant and recording sites have similar soil-amplification characteristics.

A.9.4 Recommended Response Spectra

The San Ysidro School recording is located on the ground floor of a 1-story building, whereas the Gilroy Sewage Treatment Plant recording is located in a small instrument shelter. As a result, the former is likely to be somewhat deficient in high-frequency ground motion due to wave-scattering and wave-passage effects. Further justification for these kinematic effects can be found by comparing the average horizontal response spectra plotted in Figure A-26. The San Ysidro School spectrum is lower than the Sewage Treatment Plant recording at frequencies of about 3 Hz and greater. Because of this, the San Ysidro School recording is considered to be a somewhat conservative (i.e., lower) estimate of the high-frequency amplitude of the free-field spectrum at this site. The San Ysidro School recording is used because of the uncertainty that the higher ground motion at the Sewage Treatment Plant could possibly be due in part to it being located slightly closer to the earthquake rupture or it having somewhat different soil-amplification effects.

Based on the proximity of the Calpine Plant to the two selected recordings (1.2 to 1.6 kilometers), the similar distance from each of the sites to the rupture plane of the Loma Prieta earthquake (13.0 to 14.5 kilometers), the similar epicentral azimuths of all sites from the epicenter of the earthquake (97° to 100°), the similar amplitude and spectral shapes of the two recorded response spectra (Figure A-26), and the similar soil-amplification characteristics at each of the sites, it is recommended that the average of the San Ysidro School and Gilroy Sewage Treatment Plant response spectra be used as a credible estimate of the ground motion at the Calpine Gilroy Cogeneration Plant. The recommended 5%-damped acceleration response spectrum is shown in Figure A-27. Boore (1997) did not provide an estimate of the ground motion at this site.

A.10 Watkins-Johnson Instrument Plant (Scenario 2)

The Watkins-Johnson Instrument Plant is located in the town of Scotts Valley in Santa Cruz County, California. It is located 8 kilometers west of the surface projection of the rupture plane of the October 17, 1989 moment-magnitude (M_w) 7.0 Loma Prieta earthquake.

The Loma Prieta earthquake caused widespread damage throughout the Santa Cruz and San Francisco regions (Plafker and Galloway, 1989; Stover and others, 1990). It was assigned an epicentral intensity of VIII on the Modified Mercalli Intensity (MMI) scale (MMI). However, an even higher intensity of MMI IX was assigned to San Francisco's Marina District, where widespread liquefaction occurred, and to four areas located on soft soils that experienced significant damage and collapse of elevated reinforced-concrete viaducts. These areas are the Nimitz Freeway viaduct (Interstate 880, Cyprus Section) in Oakland; and the Embarcadero, Highway 101, and Interstate 280 viaducts in San Francisco. Shaking effects consistent with MMI VIII were observed in Hollister, Los Gatos, parts of Oakland, Santa Cruz, Scotts Valley, and Watsonville, as well as in many other towns and communities in the epicentral region. Shaking intensity VII effects were observed along the west and east margins of San Francisco Bay as far north as San Francisco and Oakland.

A.10.1 Strong-Motion Recordings

There was no strong-motion recording at the Instrument Plant. The closest recording was 4.0 kilometers away at a residence on Branciforte Court in Scotts Valley (UCSC Station BRAN). The geographic coordinates of the recording site are 37.047°N latitude and 121.985°W longitude. The accelerograph, which is located at ground level in the garage of a house, recorded peak ground accelerations of 0.50*g*, 0.46*g*, and 0.50*g* in the East, North, and Vertical directions, respectively (McNally and others, 1996). The 5%-damped acceleration response spectra for the two horizontal components are shown in Figure A-28.

A.10.2 Earthquake Parameters

Earthquake parameters from seismological and wave-modeling studies are summarized in special volumes of the *Bulletin of the Seismological Society of America* (Vol. 81, No. 5), summarized by Hanks and Krawinkler (1991), and in *U.S. Geological Survey Professional Paper 1550-A*, summarized by Spudich (1996). Spudich (1996) and Eberhart-Phillips and others (1990) report the following seismological parameters for the earthquake:

Date:	October 18, 1989
Time:	4:15.2 Greenwich Mean Time
Magnitude:	7.0 M_w
Epicenter:	37.036°N, 121.883°W
Depth:	19 km
Stress Drop:	50 bar (average)
Strike:	130° (southeast)
Dip:	70° to the southwest
Rake:	130° (reverse-oblique slip)

Similar source mechanisms were obtained by many other seismologists (e.g., *Geophysical Research Letters*, vol. 17, no. 9, 1990; *Bulletin of the Seismological Society of America*, vol. 81, no. 5, 1991; *U.S. Geological Survey Professional Paper 1550-A*, 1996).

Using strong-motion and broadband teleseismic recordings, Wald and others (1996) determined the following rupture model for the earthquake:

Width (down-dip):	20 km
Length:	40 km
Depth to Top:	4–6 km
Strike:	128° (southeast)
Dip:	70° to the southwest
Rake:	142° (average; reverse-oblique slip)
Average Slip:	2.5 m (northwest section) 1.8 m (southeast section)
Seismic Moment:	2.2×10^{26} dyne-cm (northwest section) 0.8×10^{26} dyne-cm (southeast section) 3.0×10^{26} dyne-cm (total; 7.0 M_w)
Stress Drop:	218 bars (northwest section) 136 bars (southeast section

The seismic moment of 3.0×10^{26} dyne-cm (dyne-centimeters) is consistent with a moment magnitude of 7.0 based on the moment-magnitude relationship of Hanks and Kanamori (1979). Hanks and Krawinkler (1991) recommended the same "consensus value" for the moment magnitude. The fault rupture model is consistent with bilateral rupture with the largest slip towards the northwest. It is also consistent with the aftershock distribution determined by Dietz and Ellsworth (1990).

The following distances from the recording and Plant sites to the rupture plane of the Loma Prieta earthquake were calculated from the above rupture model, the epicentral coordinates reported by Spudich (1996), and the aftershock distribution determined by Plafker and Galloway (1989) and Dietz and Ellsworth (1990):

Site	Epicentral Distance (km)	Azimuth (°)	Surface Distance (km)	Rupture Distance (km)
Instrument Plant	13.1	278	7.5	14.5
BRAN	9.2	278	5.3	12.5

In this table, Rupture Distance is the shortest distance between the site and the seismogenic part of the rupture plane of the earthquake, Surface Distance is the shortest distance between the site and the surface projection of this rupture plane, and Azimuth is the angle between the epicenter and the site measured clockwise from north.

A.10.3 Local Site Conditions

There is no reliable site-specific geotechnical data for the Instrument Plant or recording sites. A geologic map of the Plant site (Clark, 1981) indicates that the buildings at the Instrument Plant are founded on the Tertiary Santa Margarita Sandstone. This sedimentary unit is a thick-bedded, well-sorted, uncemented arcosic sand that was deposited in a shallow marine environment. It reaches its maximum thickness of 130 meters approximately 2 kilometers north of Plant. The Santa Margarita Sandstone unconformably overlies the Middle Miocene Monterey Formation. The contact between the Santa Margarita Sandstone and the Monterey Formation occurs about one-kilometer west of the Plant, so the Santa Margarita Sandstone must be relatively thin beneath the Plant.

The Miocene Monterey Formation is an organic mudstone that grades upward into a sandy siltstone. The Monterey Formation is over 800 meters thick in the vicinity of the Plant. Underlying the Monterey Formation is the Middle Miocene Lompico Sandstone, which is over 150 meters thick. Therefore, relatively soft upper Tertiary sediments are at least one kilometer thick beneath the Plant.

A geologic map of the recording site (Clark and others, 1989) indicates that the Branciforte site rests on the Pliocene Purisima Formation. The Purisima Formation is a thick-bedded to massive, weakly consolidated, fine-to-medium-grained sandstone with some thick-bedded tuffaceous and diatomaceous siltstone beds. From cross-sections given by Clark and others, the Purisima Formation is about 200 feet thick beneath the Branciforte site. Underlying the Purisima Formation is the Santa Margarita Sandstone, which is approximately 80-feet thick at this location. The Santa Margarita Sandstone unconformably overlies 95 to120 million-year-old granitic rock. Therefore, relatively soft upper Tertiary sediments are only about 280-feet (85-meters) thick at the Branciforte recording site.

Based on the above information and the relationship between shear-wave velocity and geologic units in California given derived by Wills and Silva (1998), it can be concluded that both the Instrument Plant and the Branciforte recording sites can be classified at the lower end of Soil Profile Type S_C (Soft Rock and Very Dense Soil) based on the soil classification given in the 1997 *Uniform Building Code* (UBC) (ICBO, 1997). This Soil Profile Type has a shear-wave velocity in the top 30 meters that ranges between 360 and 760 m/s. Based on the above information, it can be concluded that both the recording and Plant sites have similar soil-amplification characteristics at high frequencies. However, because of the relatively thin sedimentary deposits at the Branciforte site, this site is expected to have lower amplification at low frequencies.

A.10.4 Recommended Response Spectra

The Instrument Plant, being 14.5 kilometers from the rupture plane of the Loma Prieta earthquake, is about 2 kilometers further from this plane than the Branciforte recording site (12.5 kilometers). However the epicentral azimuths are identical for these two sites, so the kinematic and dynamic fault rupture characteristics are expected to be the same. Therefore, based on seismological characteristics alone, the Branciforte recording is expected to have generally similar, although possibly somewhat unconservative (i.e., higher), ground motion than the Plant site.

The Plant and recording sites are both founded on soft sedimentary rock and have the same Soil Profile Type defined in the 1997 UBC. However, these deposits are thinner at the Branciforte site. The thinner deposits would tend to reduce the ground-motion amplitudes at low frequencies and possibly reduce the amplitudes at moderate-to-high frequencies, although not as much, as compared to the Plant site. Therefore, although the soil classification is the same, the soil-amplification is expected to be lower at the

Branciforte site. This would tend to offset the somewhat higher ground motion that is expected because the site is located closer to the earthquake rupture.

Based on the above discussion, it can be concluded that the Branciforte recording is a credible estimate of the ground motion at the Watkins-Johnson Instrument Plant from the Loma Prieta earthquake. The recommended 5%-damped acceleration response spectrum is shown in Figure A-29. Boore (1997) did not provide an estimate of the ground motion at this site.

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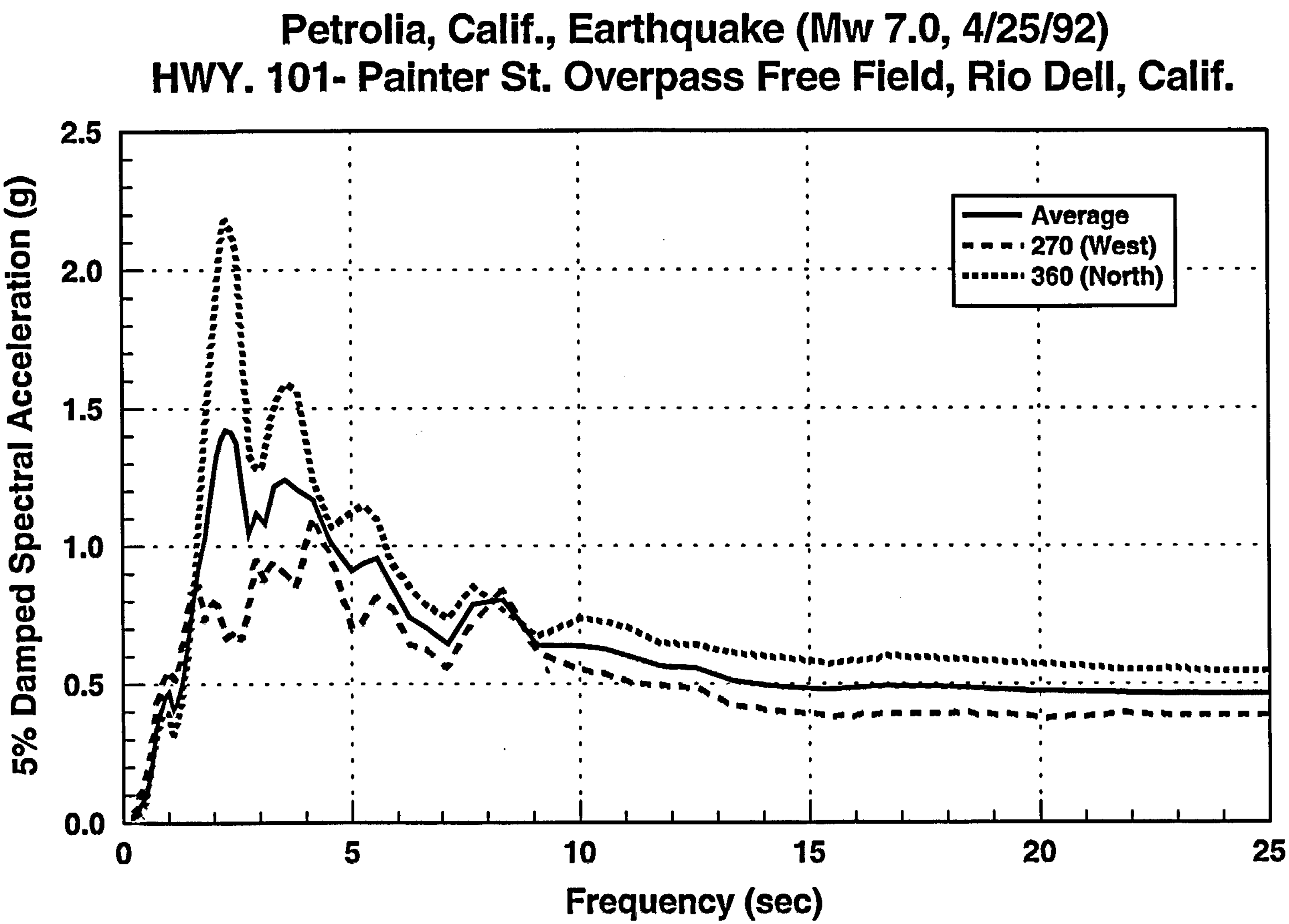
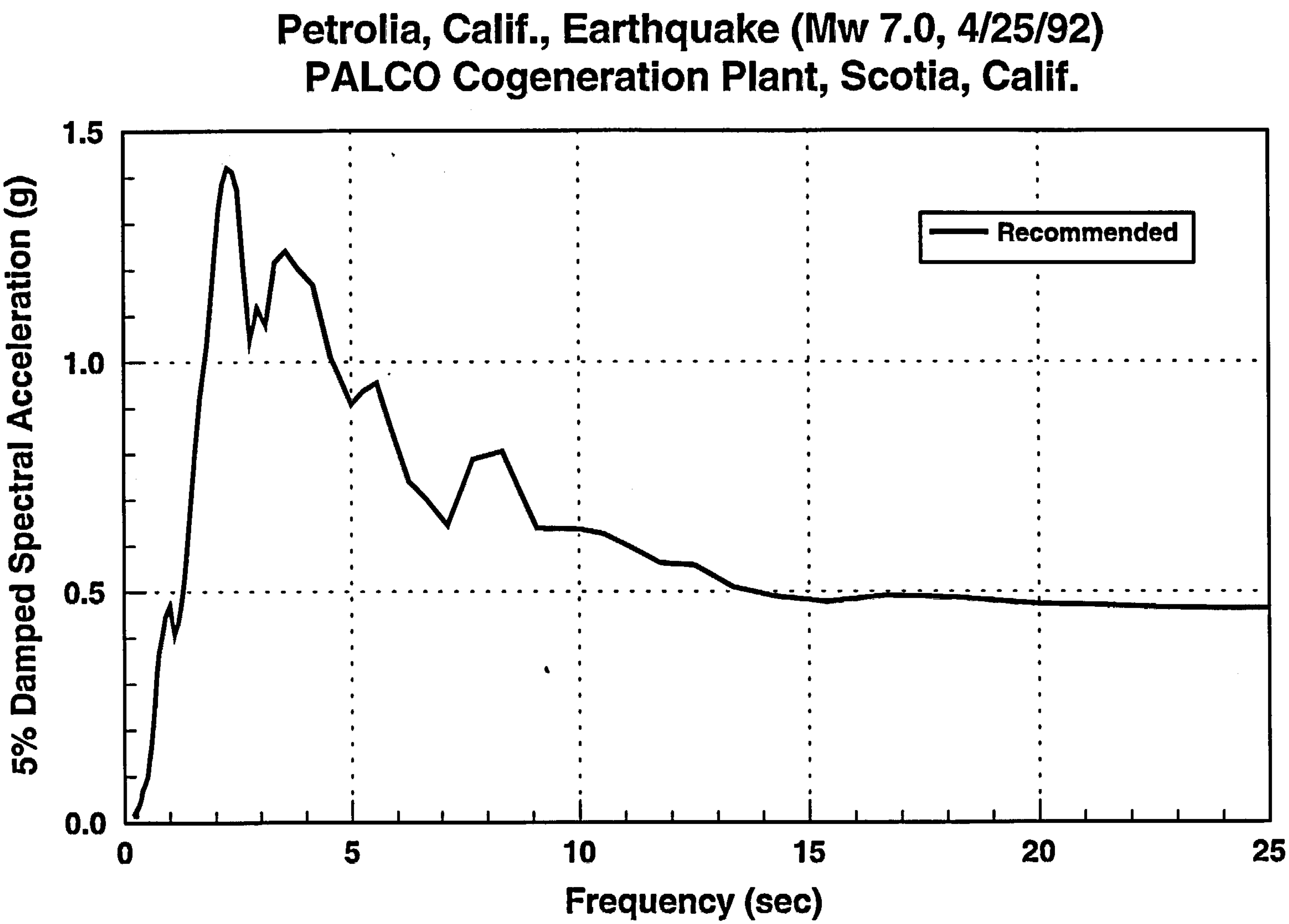
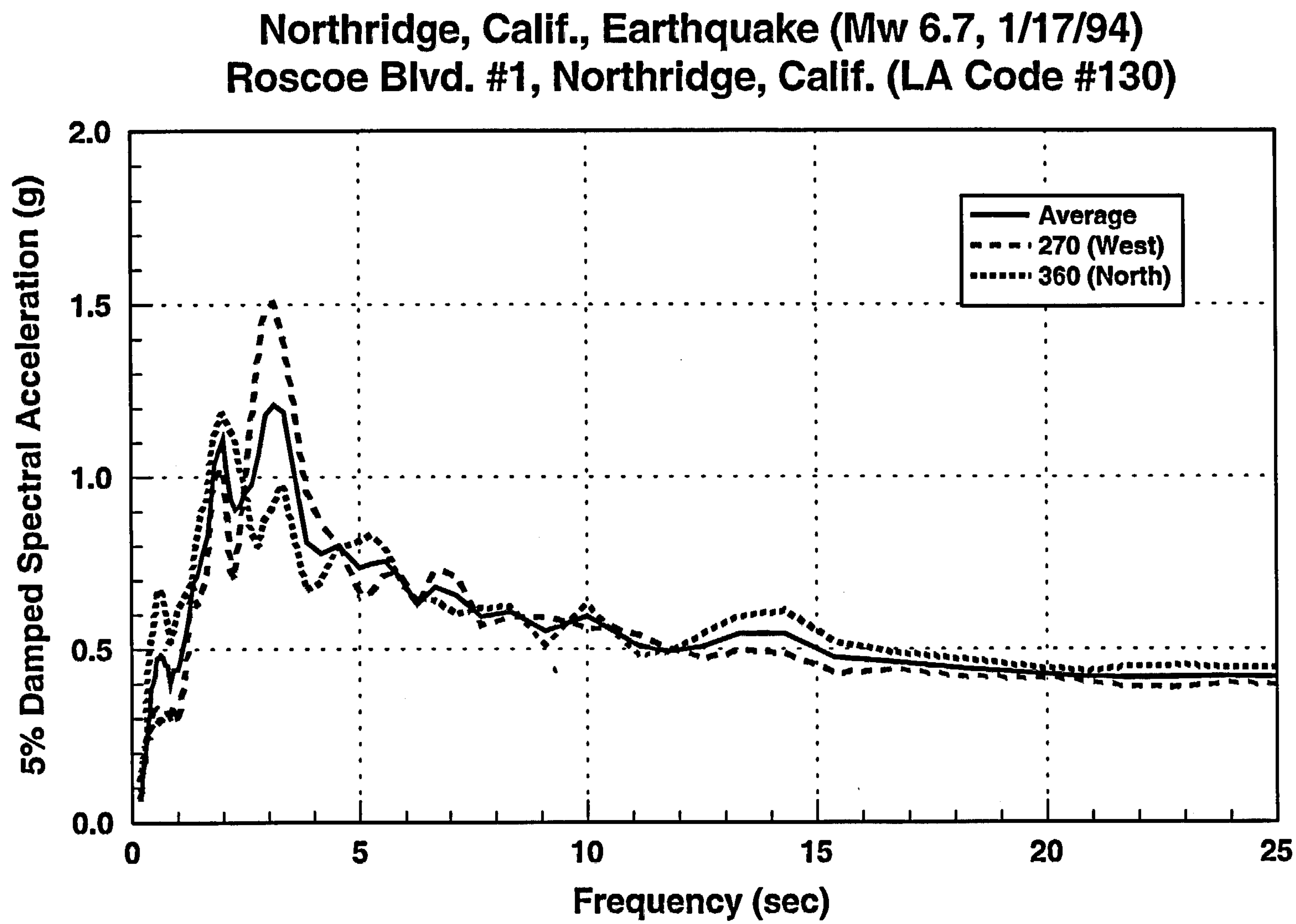

Petrolia, Calif., Earthquake (Mw 7.0, 4/25/92)
HWY. 101- Painter St. Overpass Free Field, Rio Dell, Calif.
5% Damped Spectral Acceleration (g)
Frequency (sec)
Average
270 (West)
360 (North)
0.0
0.5
1.0
1.5
2.0
2.5
0
5
10
15
20
25

Figure A-1



Petrolia, Calif., Earthquake (Mw 7.0, 4/25/92)
PALCO Cogeneration Plant, Scotia, Calif.
5% Damped Spectral Acceleration (g)
1.5
1.0
0.5
0.0
0
5
10
15
20
25
Frequency (sec)
Recommended

Figure A-2



Northridge, Calif., Earthquake (Mw 6.7, 1/17/94)
Roscoe Blvd. #1, Northridge, Calif. (LA Code #130)
5% Damped Spectral Acceleration (g)
2.0
1.5
1.0
0.5
0.0
0
5
10
15
20
25
Frequency (sec)
Average
270 (West)
360 (North)

Figure A-3

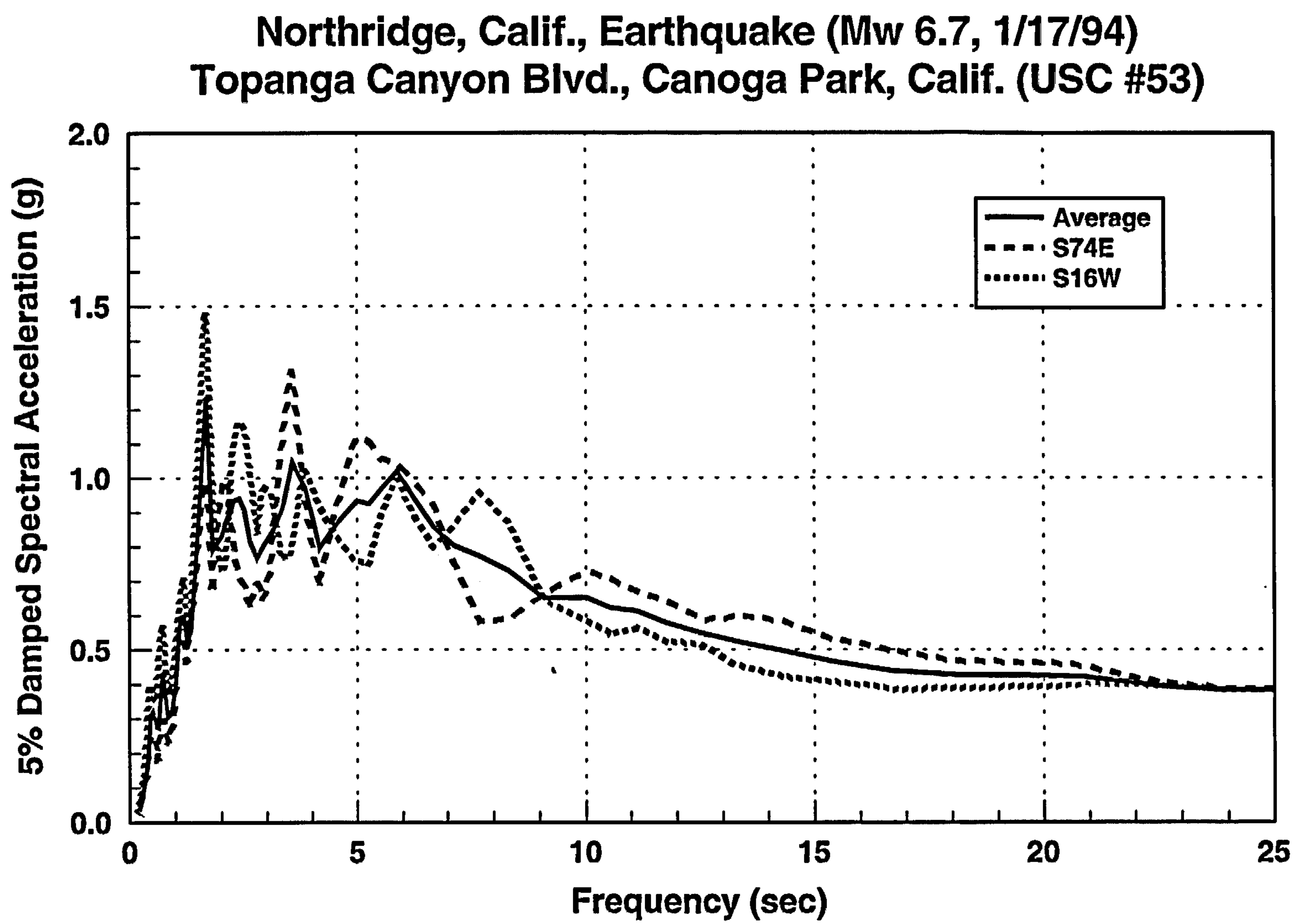

Northridge, Calif., Earthquake (Mw 6.7, 1/17/94)
Topanga Canyon Blvd., Canoga Park, Calif. (USC #53)
5% Damped Spectral Acceleration (g)
2.0
1.5
1.0
0.5
0.0
0
5
10
15
20
25
Frequency (sec)
Average
S74E
S16W

Figure A-4

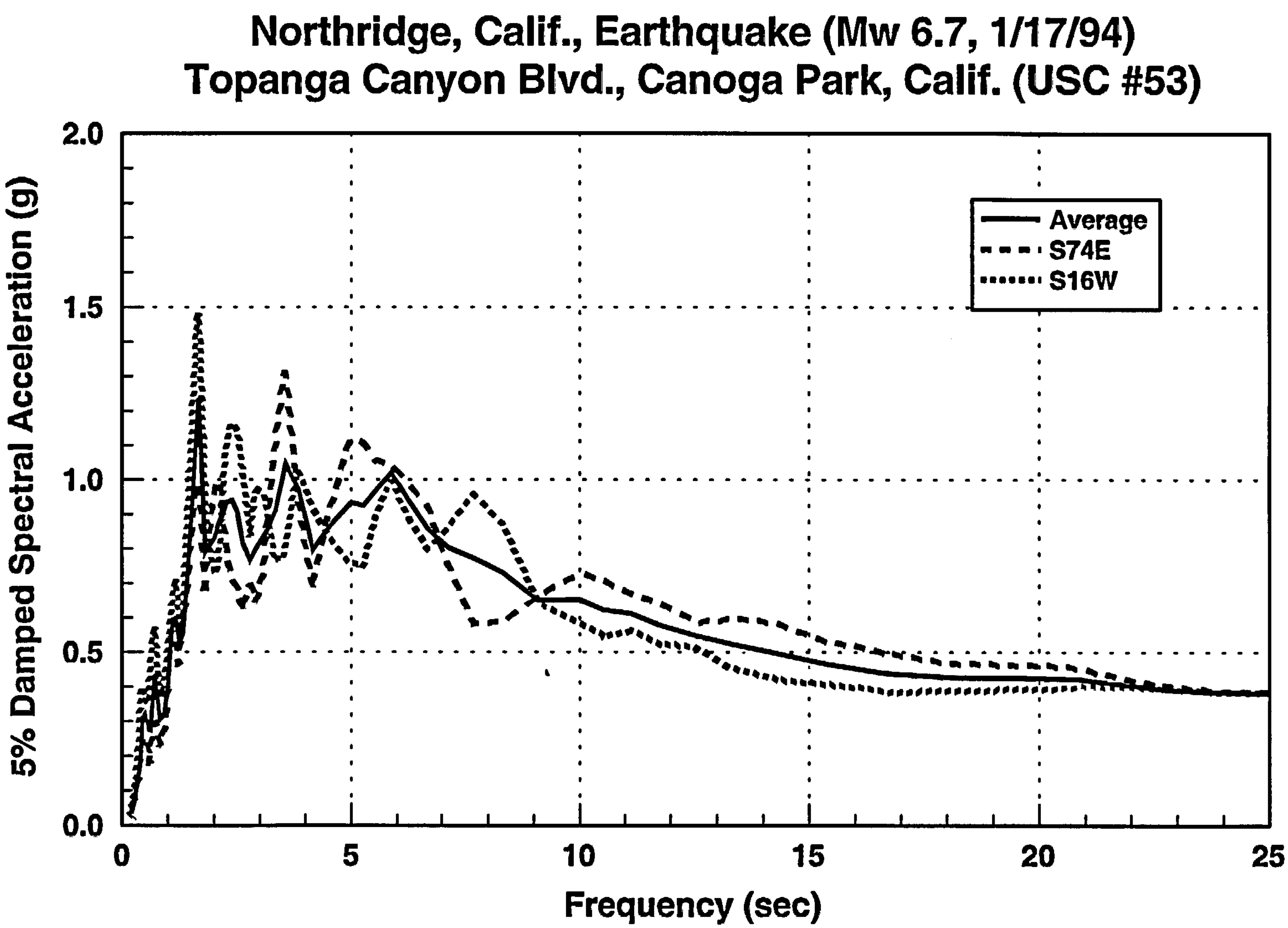
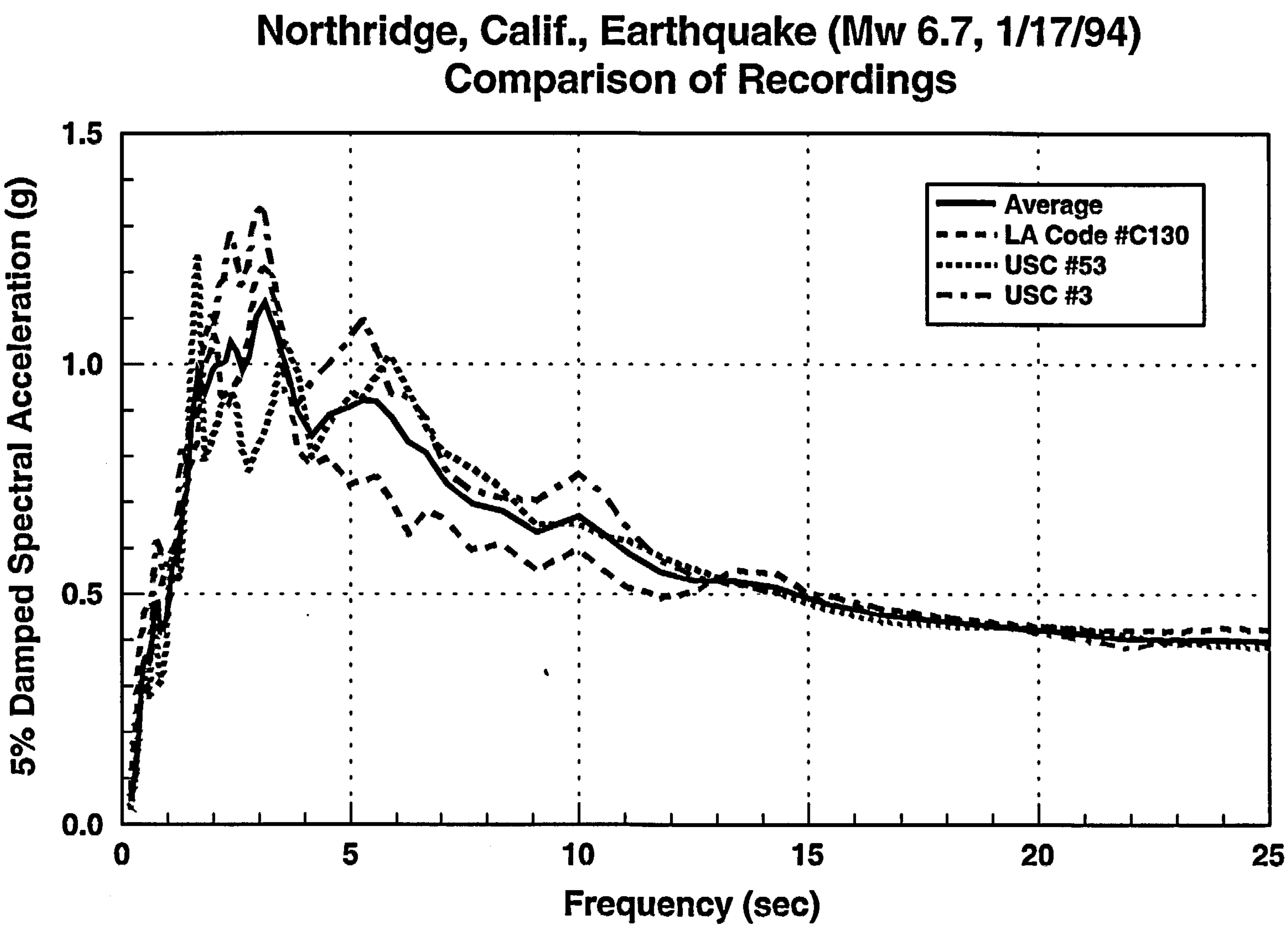

Northridge, Calif., Earthquake (Mw 6.7, 1/17/94)
Topanga Canyon Blvd., Canoga Park, Calif. (USC #53)
5% Damped Spectral Acceleration (g)
Frequency (sec)
Average
S74E
S16W
0.0
0.5
1.0
1.5
2.0
0
5
10
15
20
25

Figure A-5



Northridge, Calif., Earthquake (Mw 6.7, 1/17/94)
Comparison of Recordings
5% Damped Spectral Acceleration (g)
1.5
1.0
0.5
0.0
0
5
10
15
20
25
Frequency (sec)
Average
LA Code #C130
USC #53
USC #3

Figure A-6

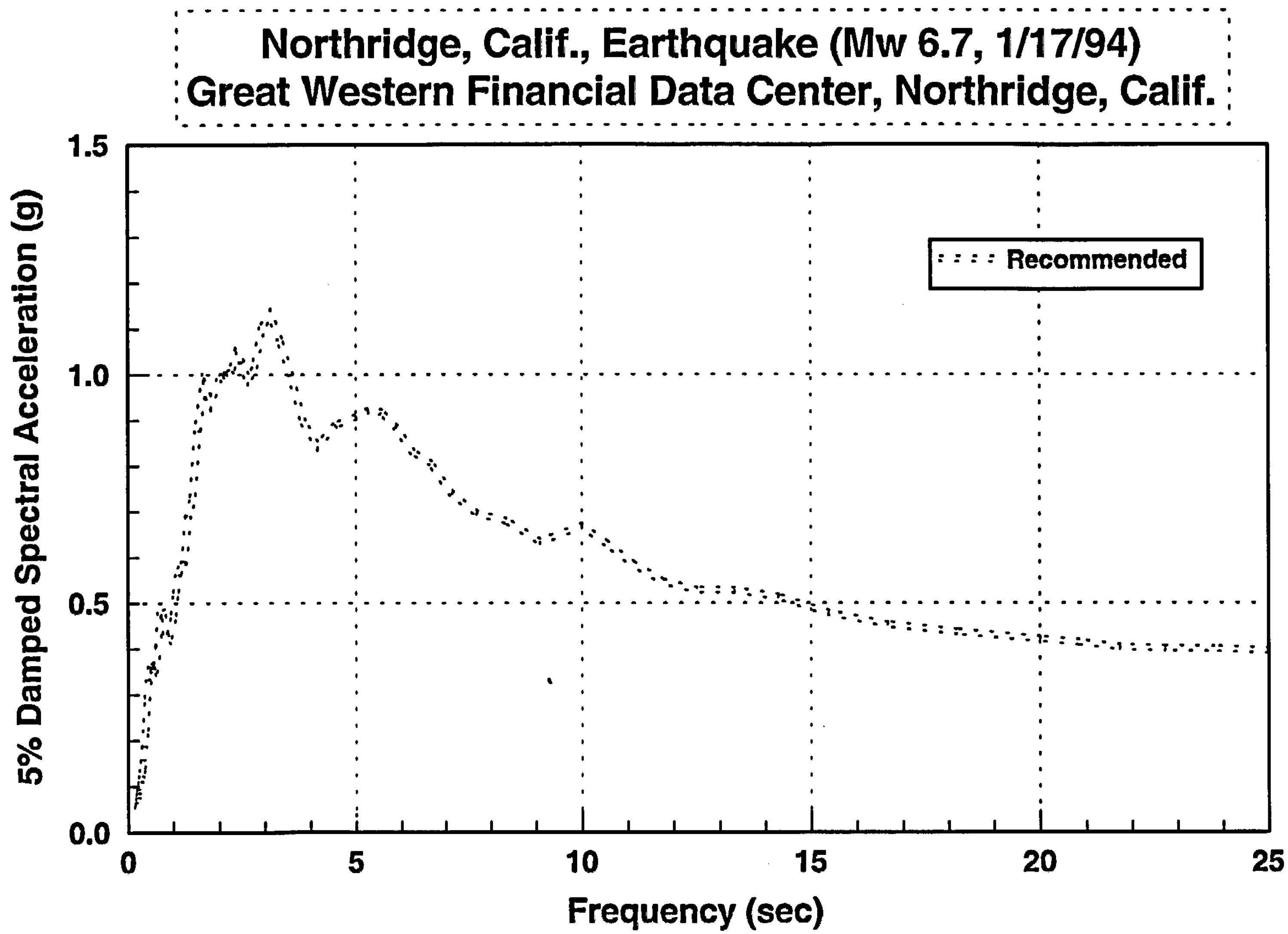
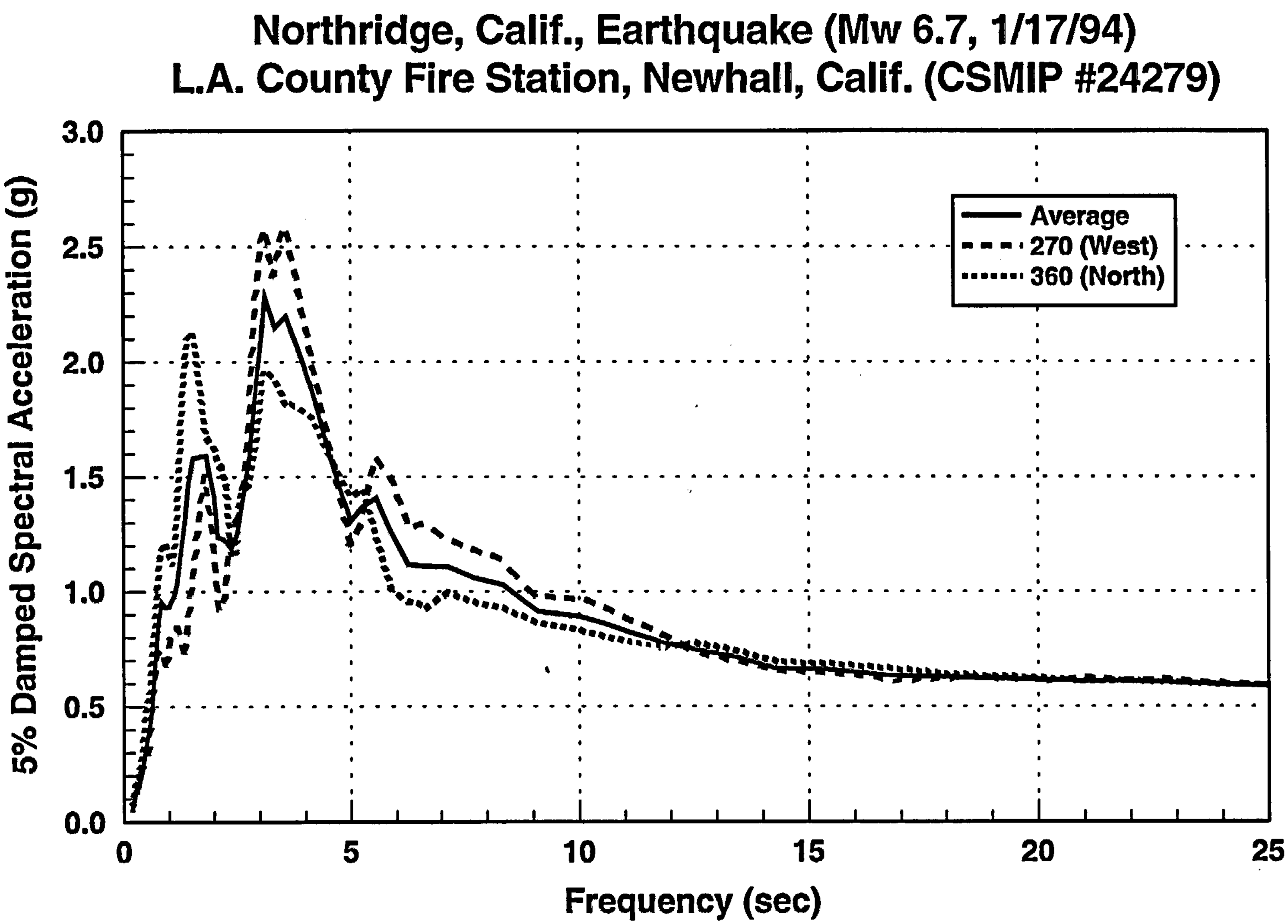

Northridge, Calif., Earthquake (Mw 6.7, 1/17/94)
Great Western Financial Data Center, Northridge, Calif.
Recommended
5% Damped Spectral Acceleration (g)
0.0
0.5
1.0
1.5
0
5
10
15
20
25
Frequency (sec)

Figure A-7



Northridge, Calif., Earthquake (Mw 6.7, 1/17/94)
L.A. County Fire Station, Newhall, Calif. (CSMIP #24279)
5% Damped Spectral Acceleration (g)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
5
10
15
20
25
Frequency (sec)
Average
270 (West)
360 (North)

Figure A-8

Northridge, Calif., Earthquake (Mw 6.7, 1/17/94)
Placerita Cogeneration Plant, Newhall, Calif.

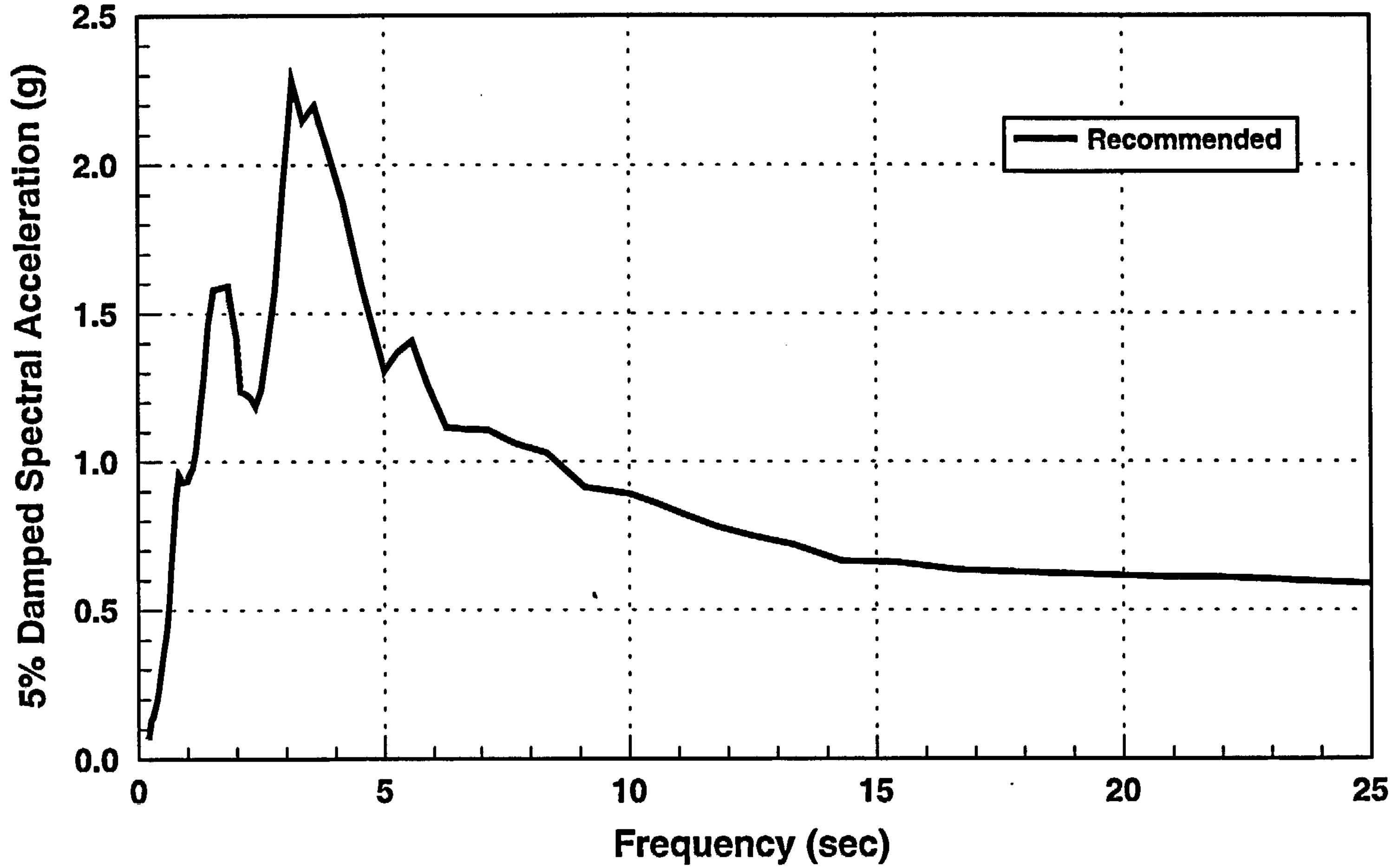


Figure A-9

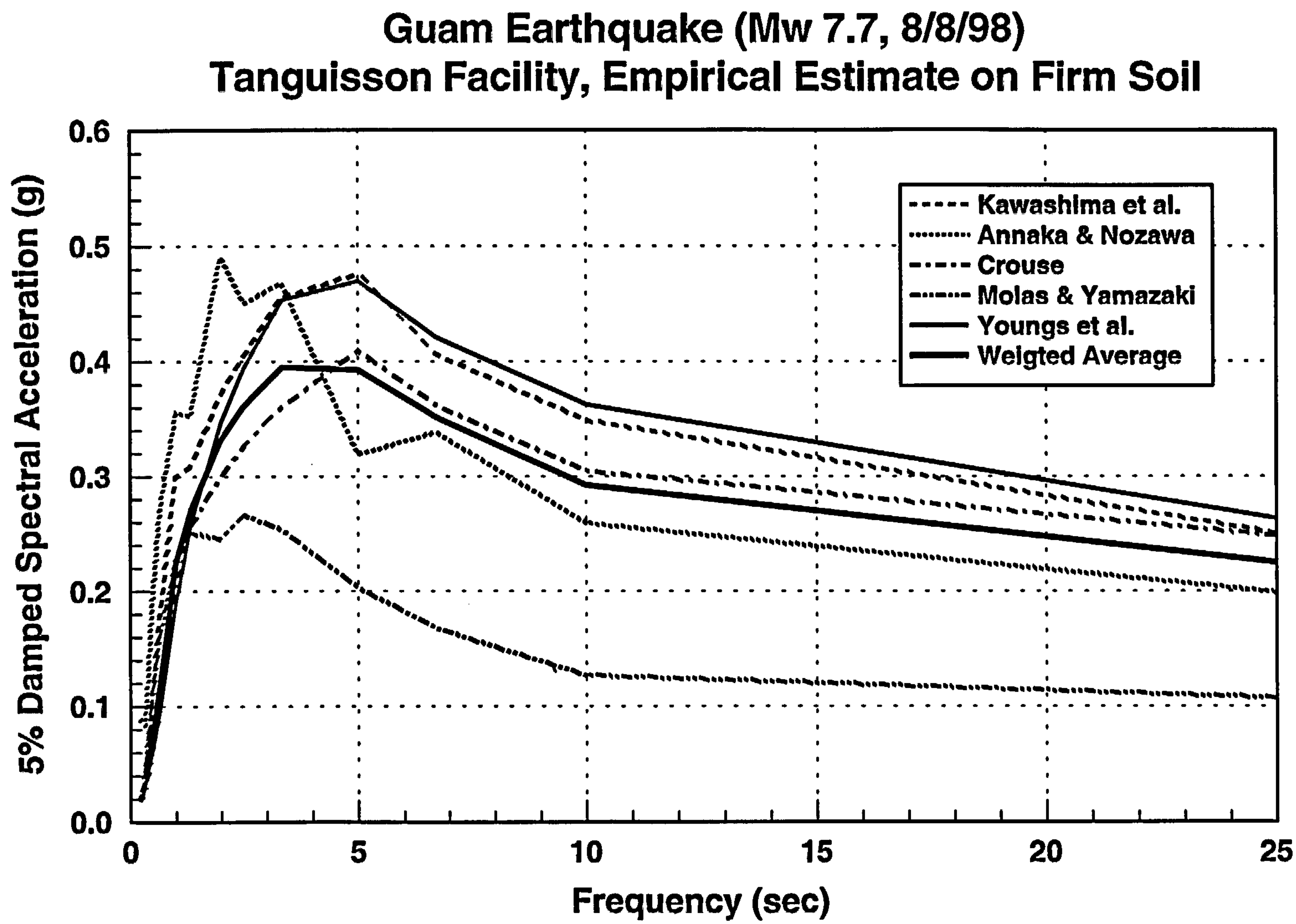

Guam Earthquake (Mw 7.7, 8/8/98)
Tanguisson Facility, Empirical Estimate on Firm Soil
5% Damped Spectral Acceleration (g)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0
5
10
15
20
25
Frequency (sec)
Kawashima et al.
Annaka & Nozawa
Crouse
Molas & Yamazaki
Youngs et al.
Weigted Average

Figure A-10

Guam Earthquake (Mw 7.7, 8/8/98)
Tanguisson Facility, Empirical Estimate on Rock

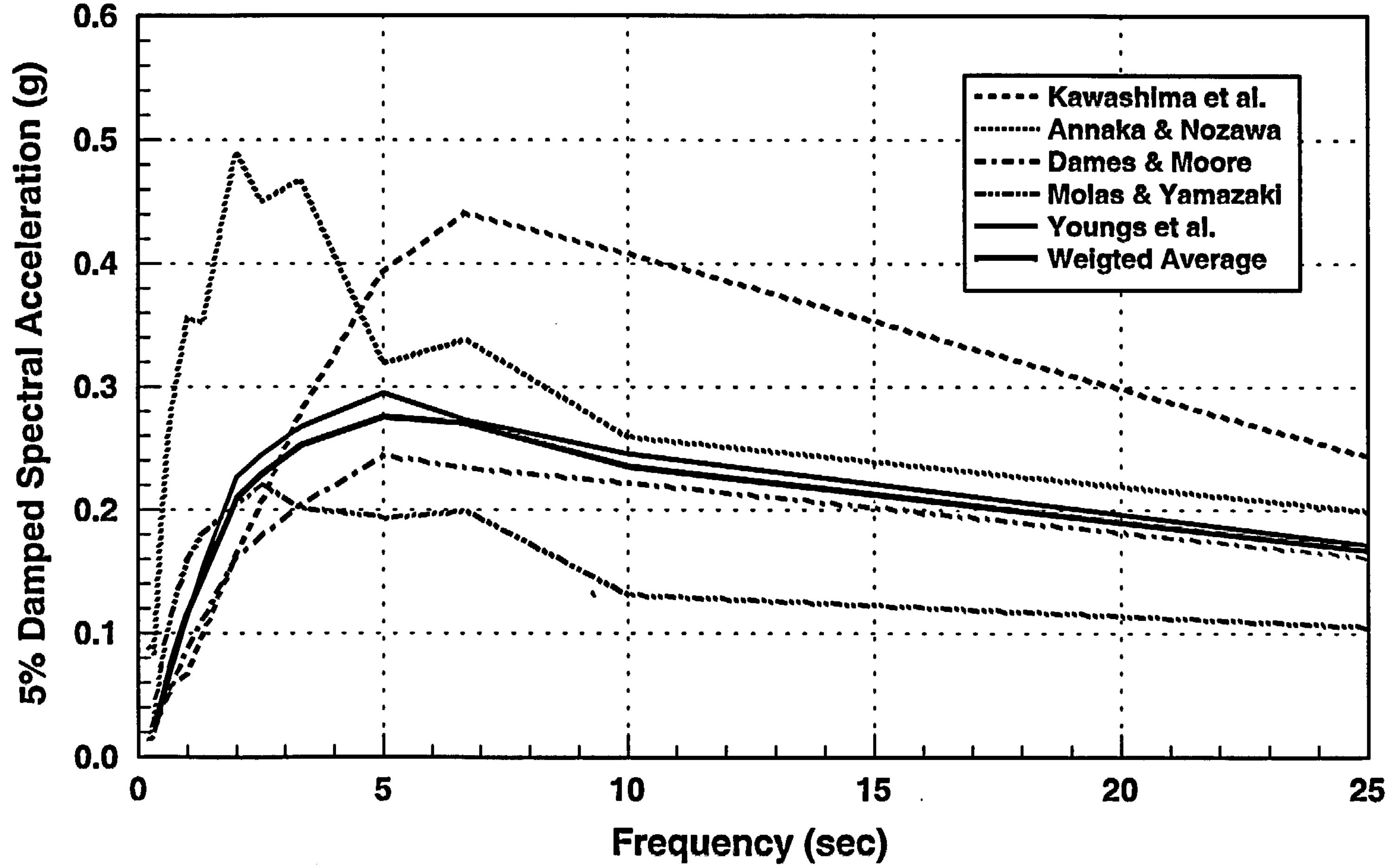


Figure A-11

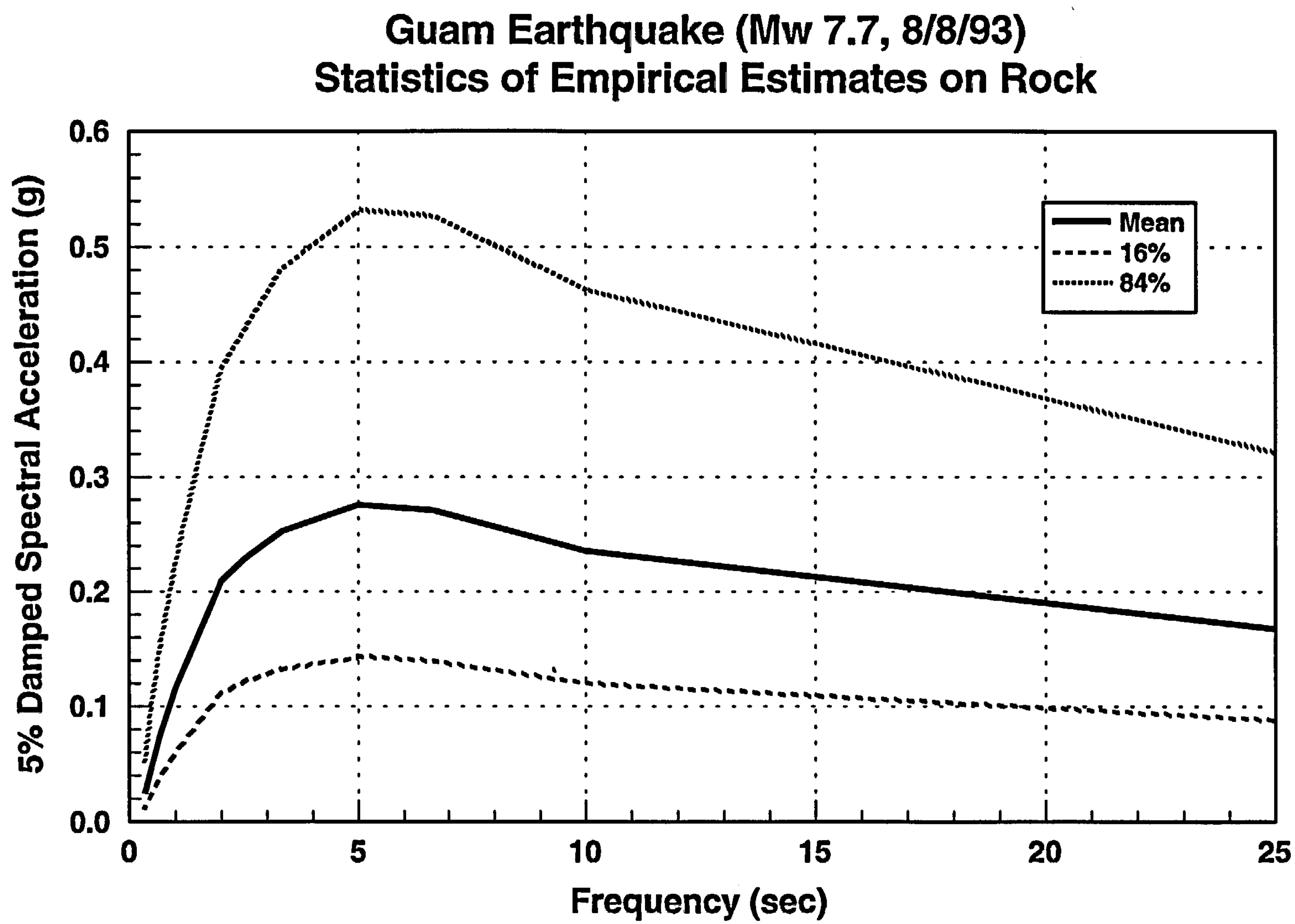

Guam Earthquake (Mw 7.7, 8/8/93)
Statistics of Empirical Estimates on Rock
5% Damped Spectral Acceleration (g)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0
5
10
15
20
25
Frequency (sec)
Mean
16%
84%

Figure A-12

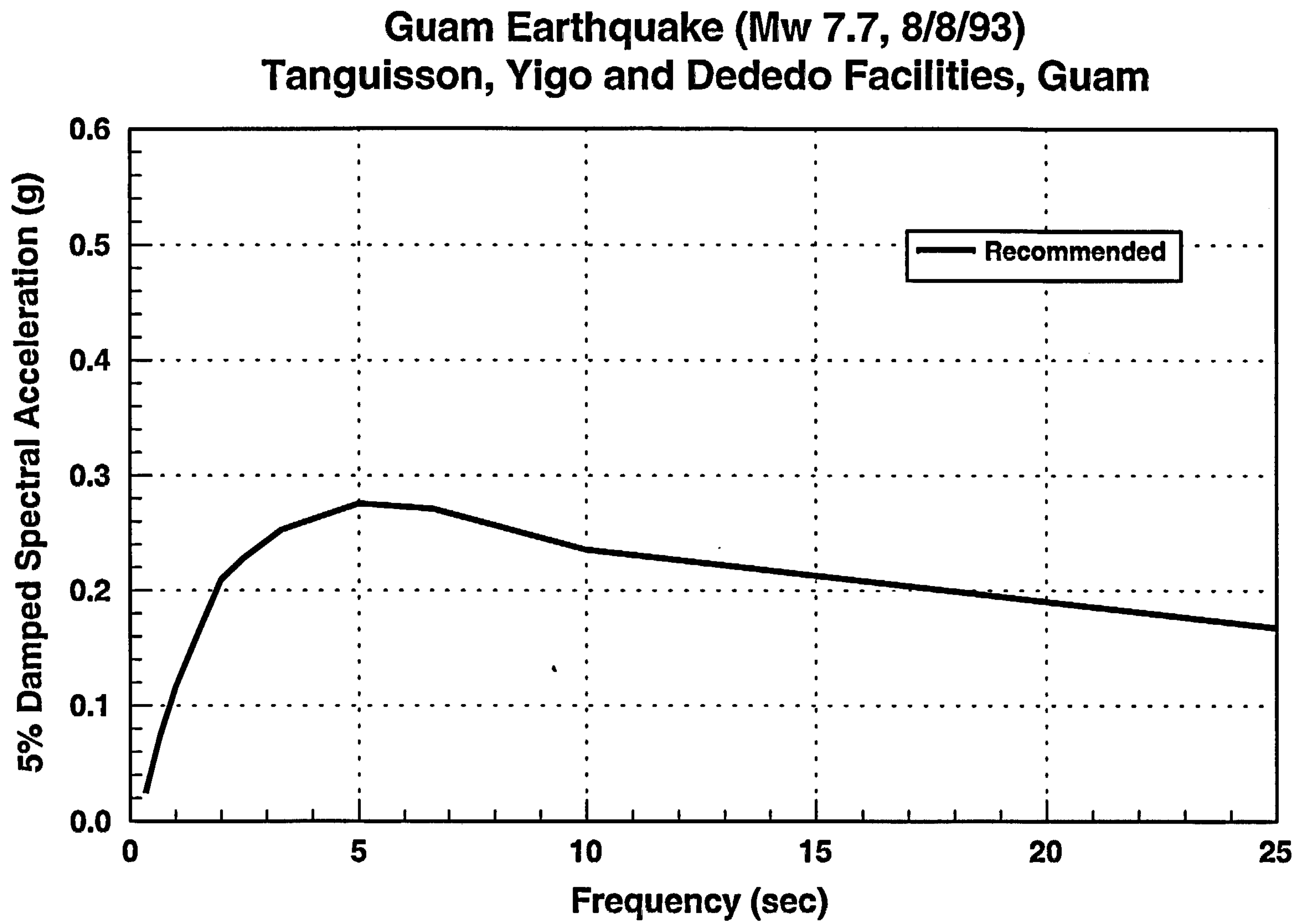

Guam Earthquake (Mw 7.7, 8/8/93)
Tanguisson, Yigo and Dededo Facilities, Guam
5% Damped Spectral Acceleration (g)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0
5
10
15
20
25
Frequency (sec)
Recommended

Figure A-13

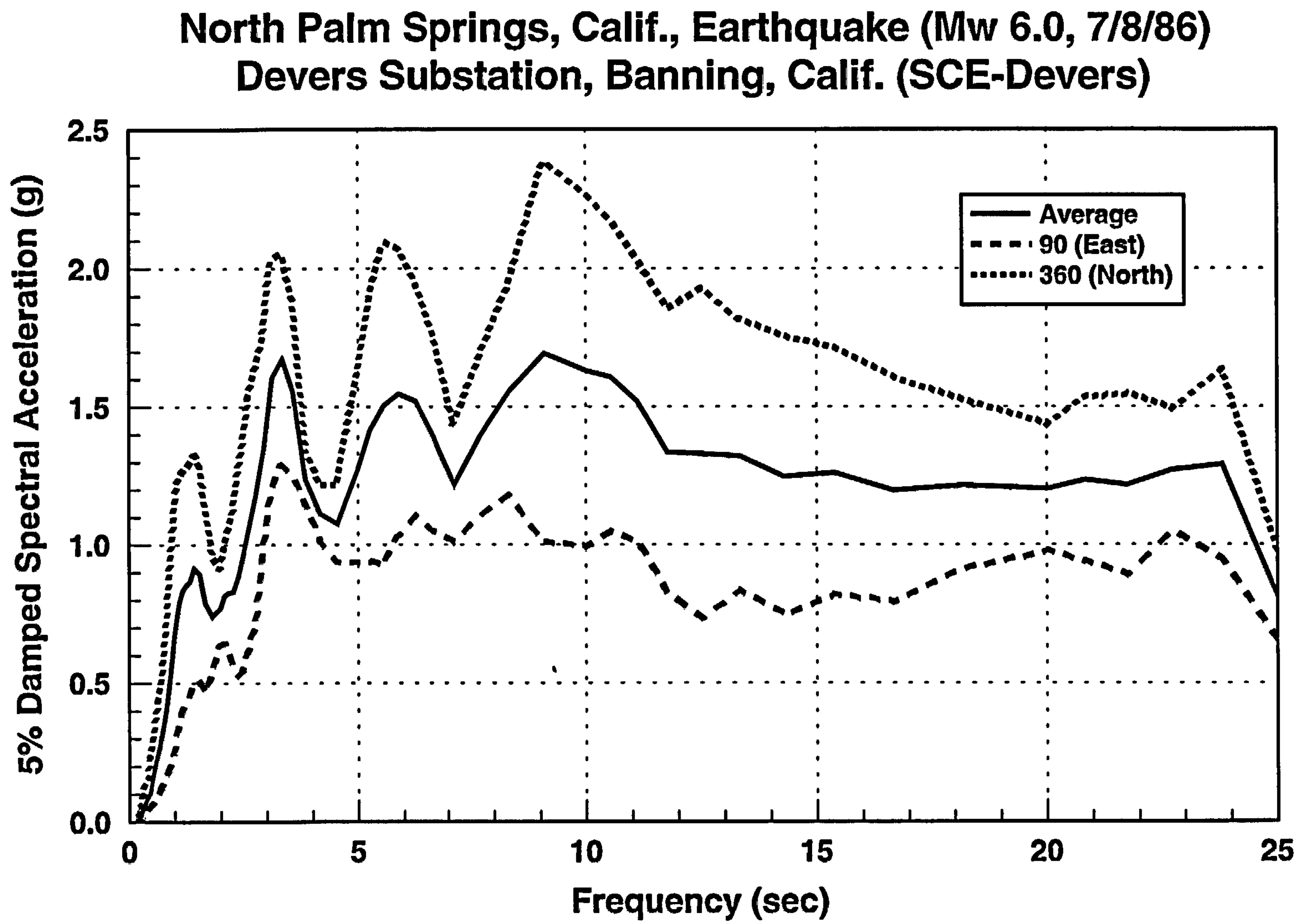

North Palm Springs, Calif., Earthquake (Mw 6.0, 7/8/86)
Devers Substation, Banning, Calif. (SCE-Devers)
5% Damped Spectral Acceleration (g)
Frequency (sec)
Average
90 (East)
360 (North)
0.0
0.5
1.0
1.5
2.0
2.5
0
5
10
15
20
25

Figure A-14

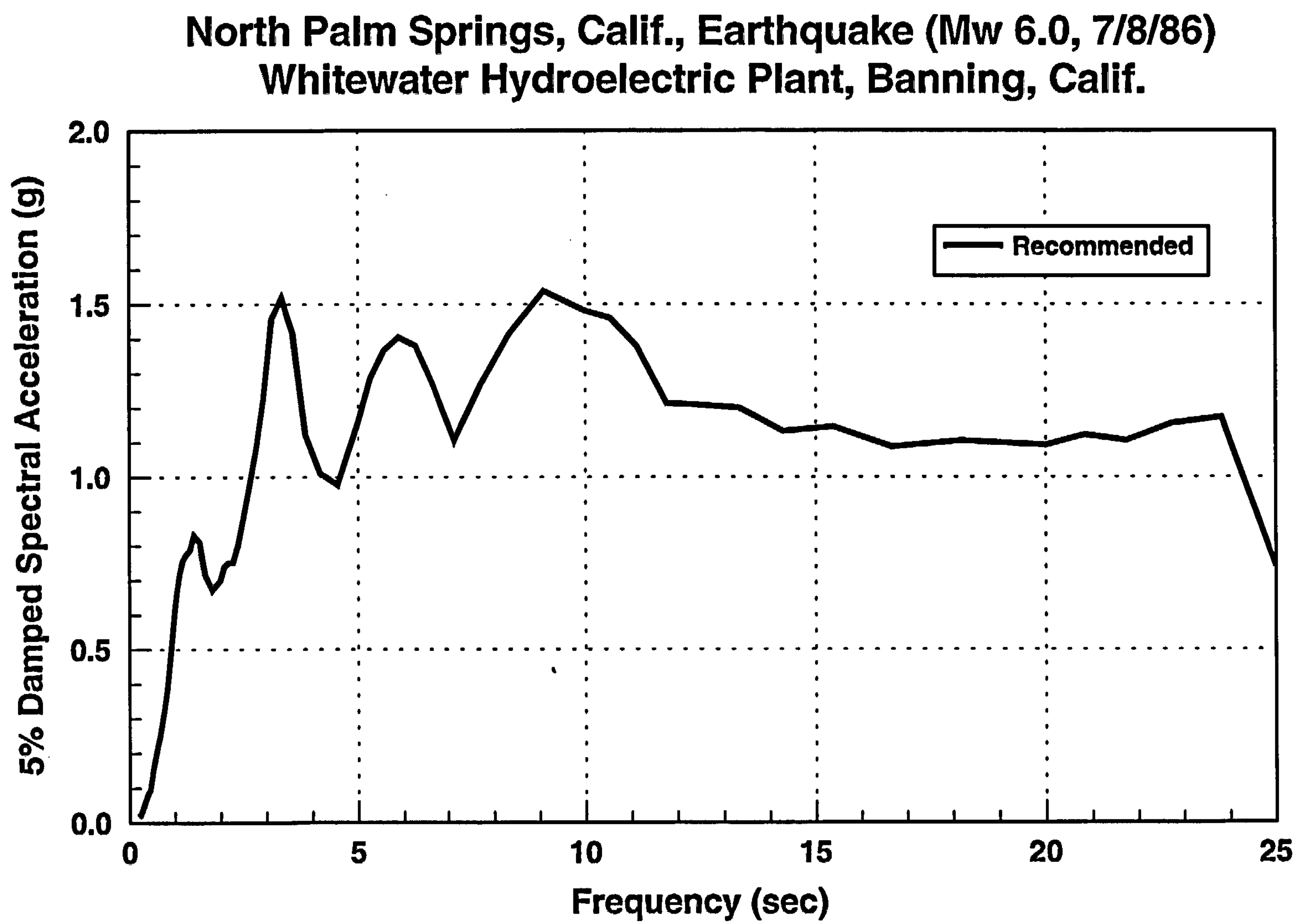

North Palm Springs, Calif., Earthquake (Mw 6.0, 7/8/86)
Whitewater Hydroelectric Plant, Banning, Calif.
Recommended
5% Damped Spectral Acceleration (g)
2.0
1.5
1.0
0.5
0.0
0
5
10
15
20
25
Frequency (sec)

Figure A-15

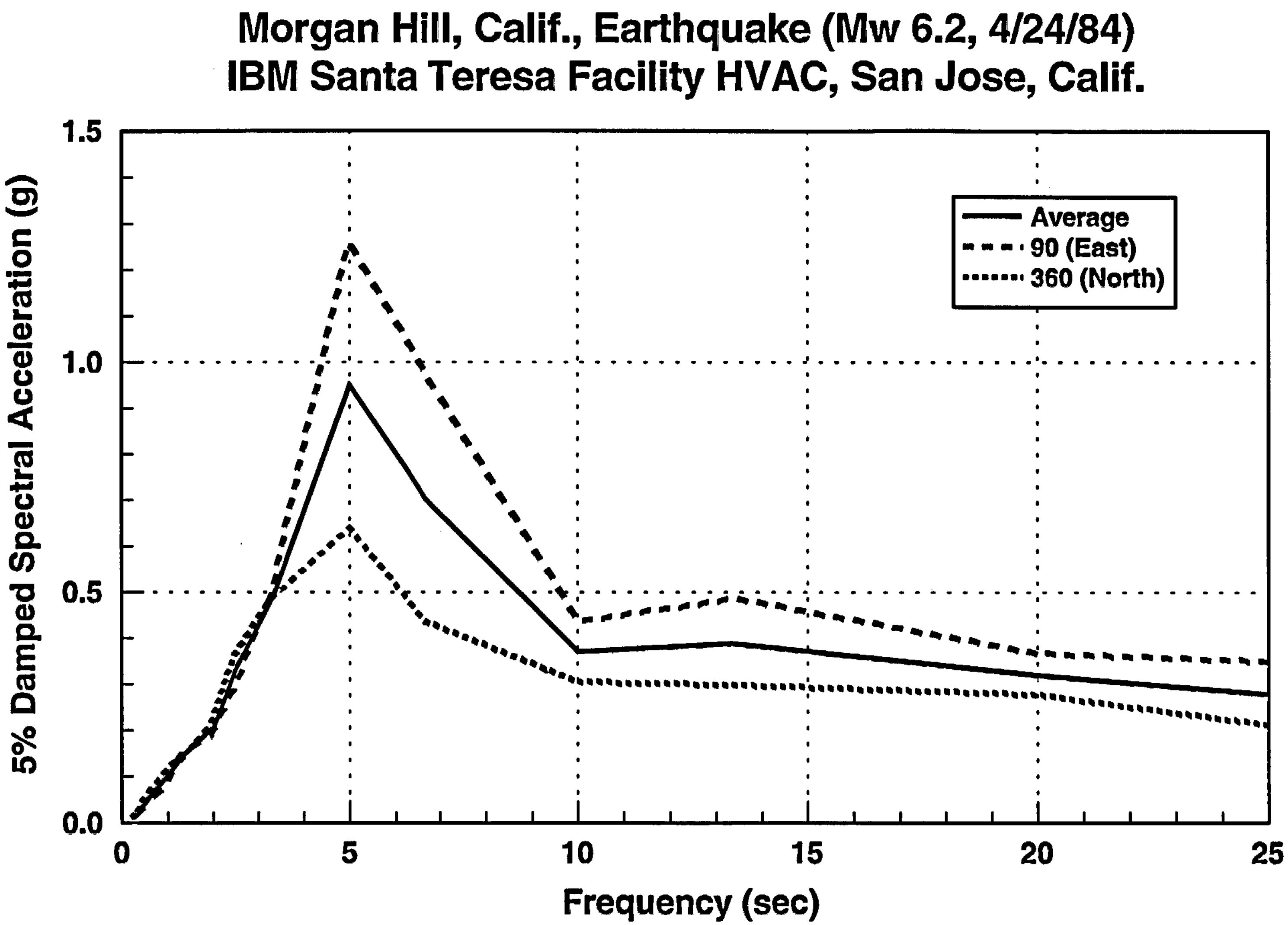

Morgan Hill, Calif., Earthquake (Mw 6.2, 4/24/84)
IBM Santa Teresa Facility HVAC, San Jose, Calif.
5% Damped Spectral Acceleration (g)
Frequency (sec)
Average
90 (East)
360 (North)
0.0
0.5
1.0
1.5
0
5
10
15
20
25

Figure A-16

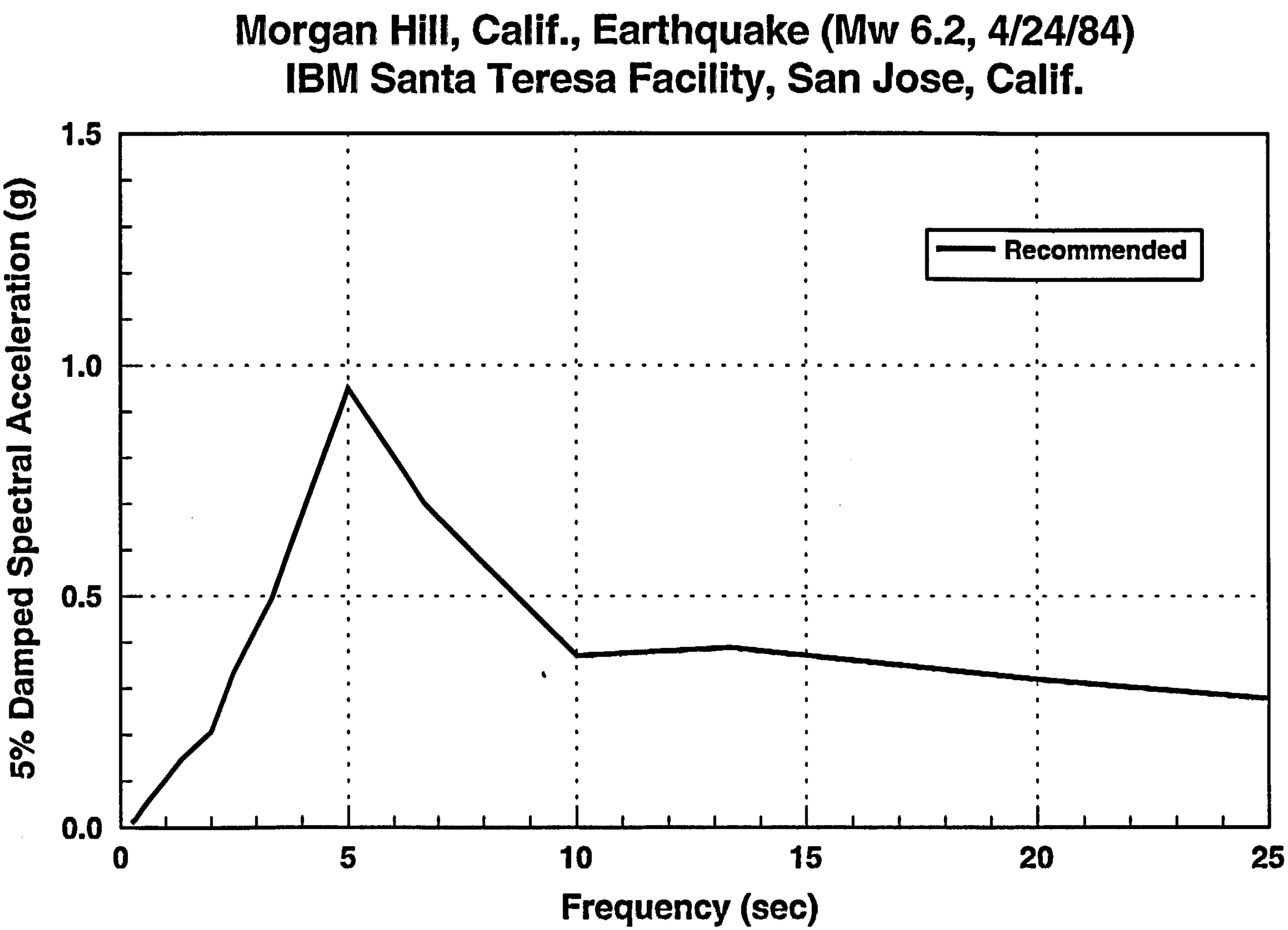

Morgan Hill, Calif., Earthquake (Mw 6.2, 4/24/84)
IBM Santa Teresa Facility, San Jose, Calif.
5% Damped Spectral Acceleration (g)
1.5
1.0
0.5
0.0
0
5
10
15
20
25
Frequency (sec)
Recommended

Figure A-17

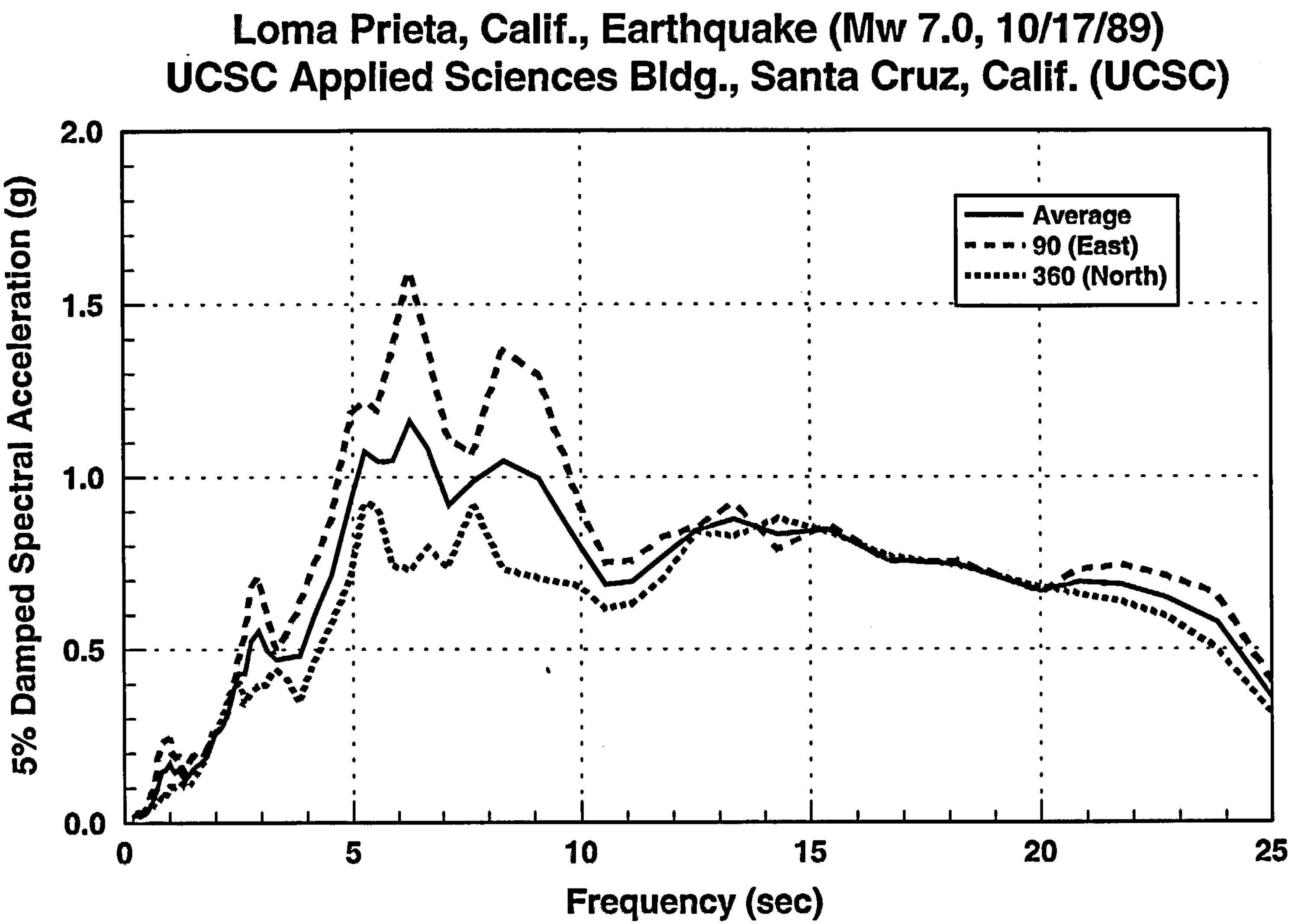

Loma Prieta, Calif., Earthquake (Mw 7.0, 10/17/89)
UCSC Applied Sciences Bldg., Santa Cruz, Calif. (UCSC)
5% Damped Spectral Acceleration (g)
2.0
1.5
1.0
0.5
0.0
0
5
10
15
20
25
Frequency (sec)
Average
90 (East)
360 (North)

Figure A-18

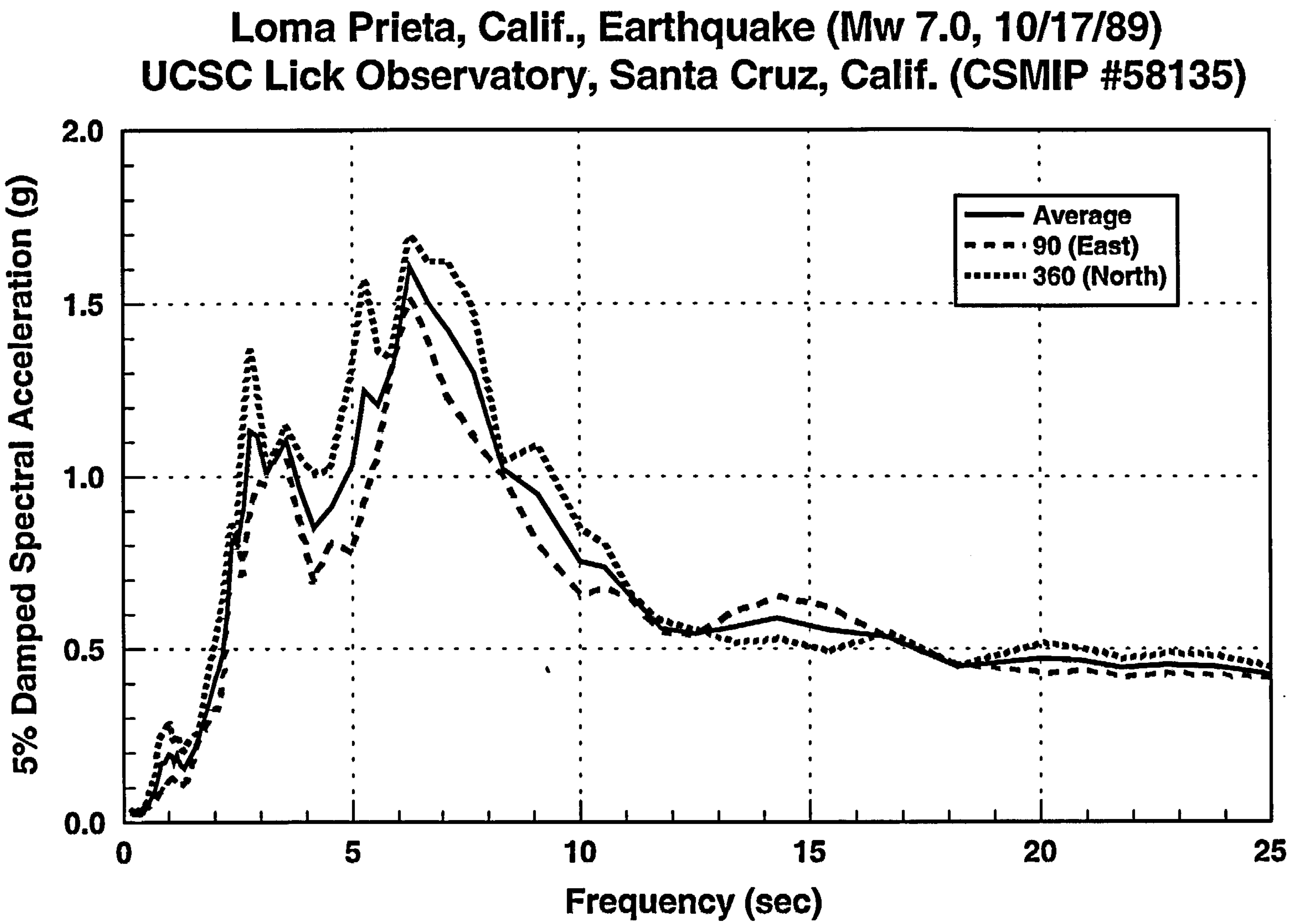

Loma Prieta, Calif., Earthquake (Mw 7.0, 10/17/89)
UCSC Lick Observatory, Santa Cruz, Calif. (CSMIP #58135)
5% Damped Spectral Acceleration (g)
Frequency (sec)
Average
90 (East)
360 (North)
0.0
0.5
1.0
1.5
2.0
0
5
10
15
20
25

Figure A-19

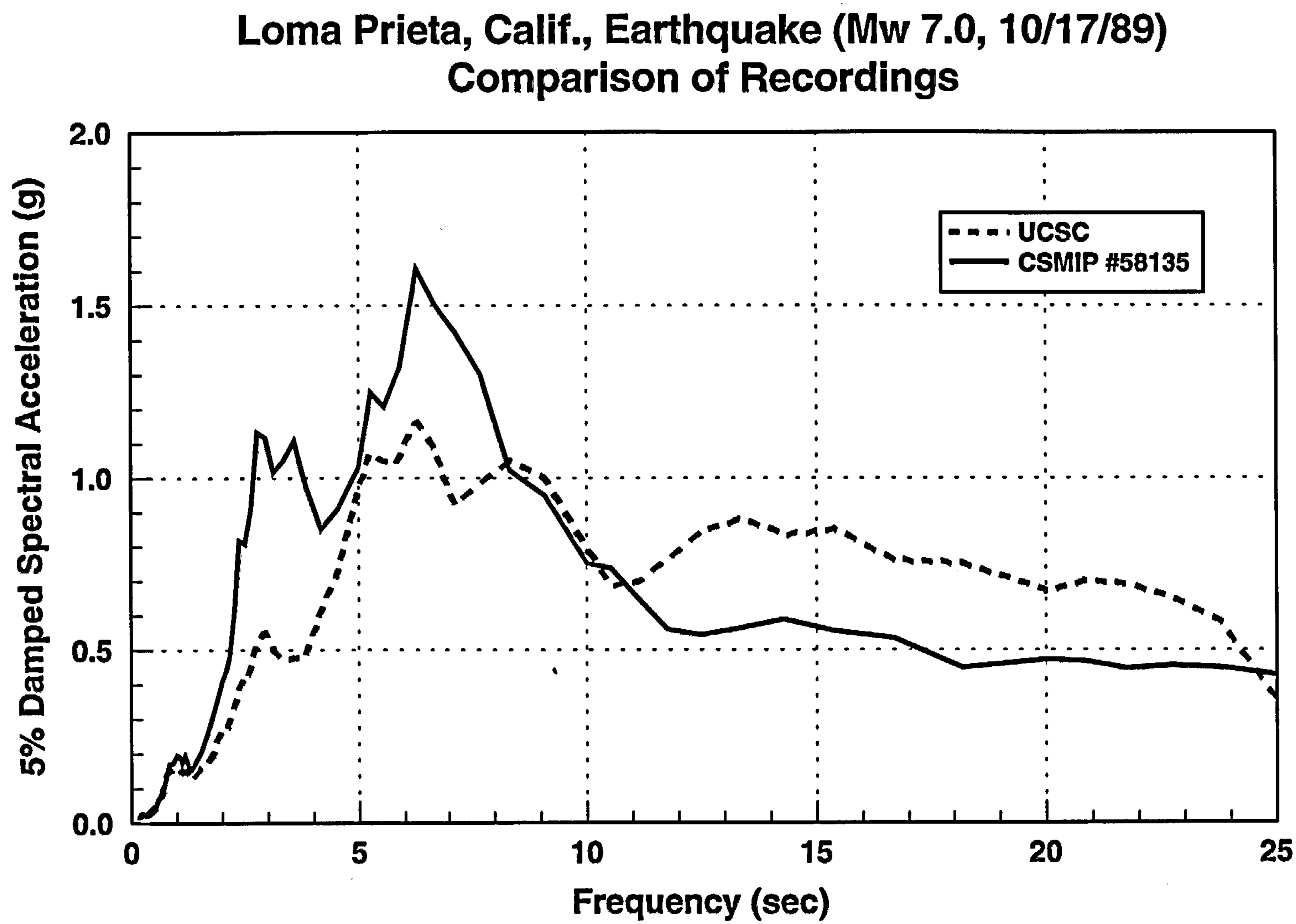

Loma Prieta, Calif., Earthquake (Mw 7.0, 10/17/89)
Comparison of Recordings
UCSC
CSMIP #58135
5% Damped Spectral Acceleration (g)
Frequency (sec)
2.0
1.5
1.0
0.5
0.0
0
5
10
15
20
25

Figure A-20

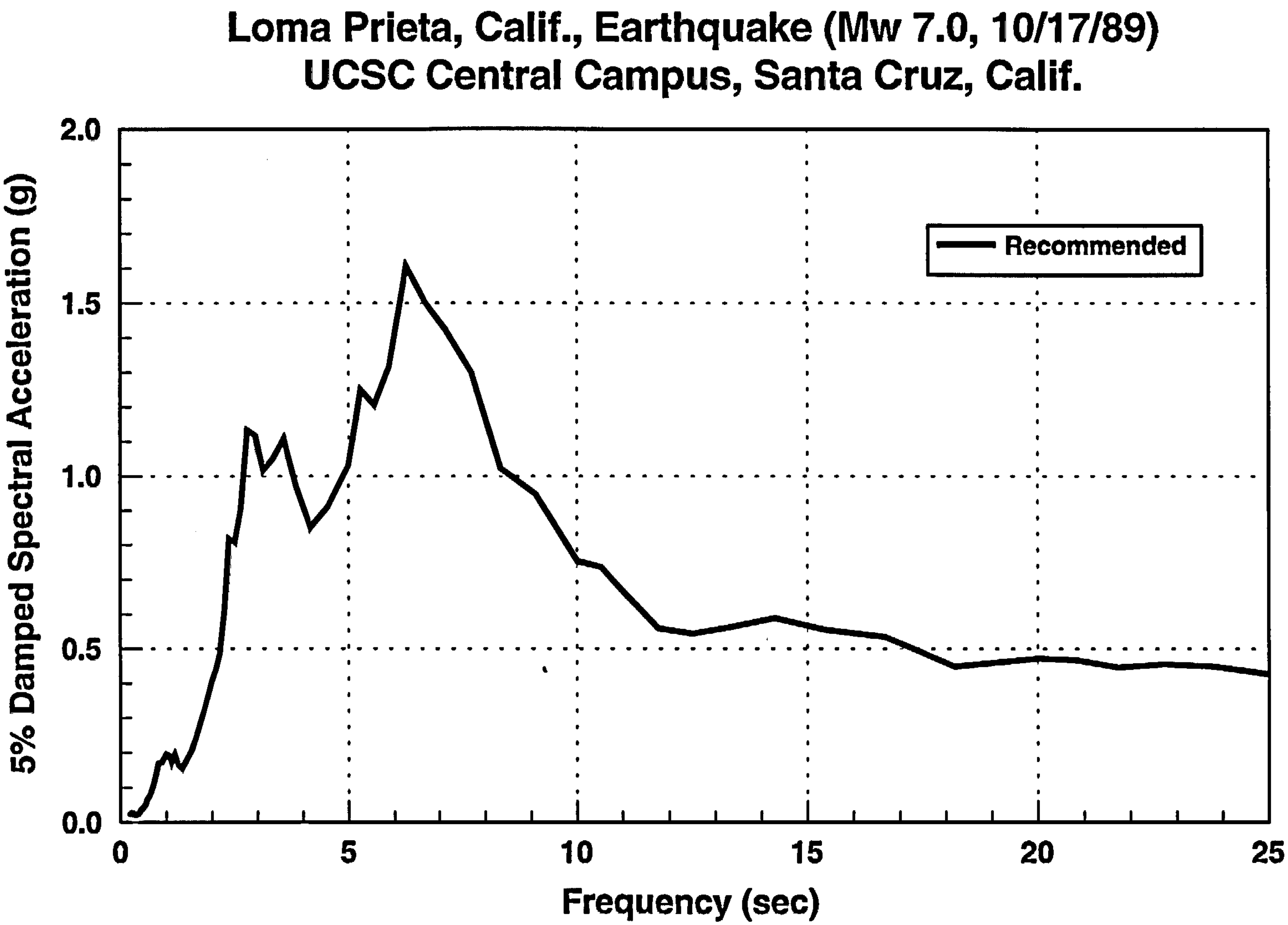
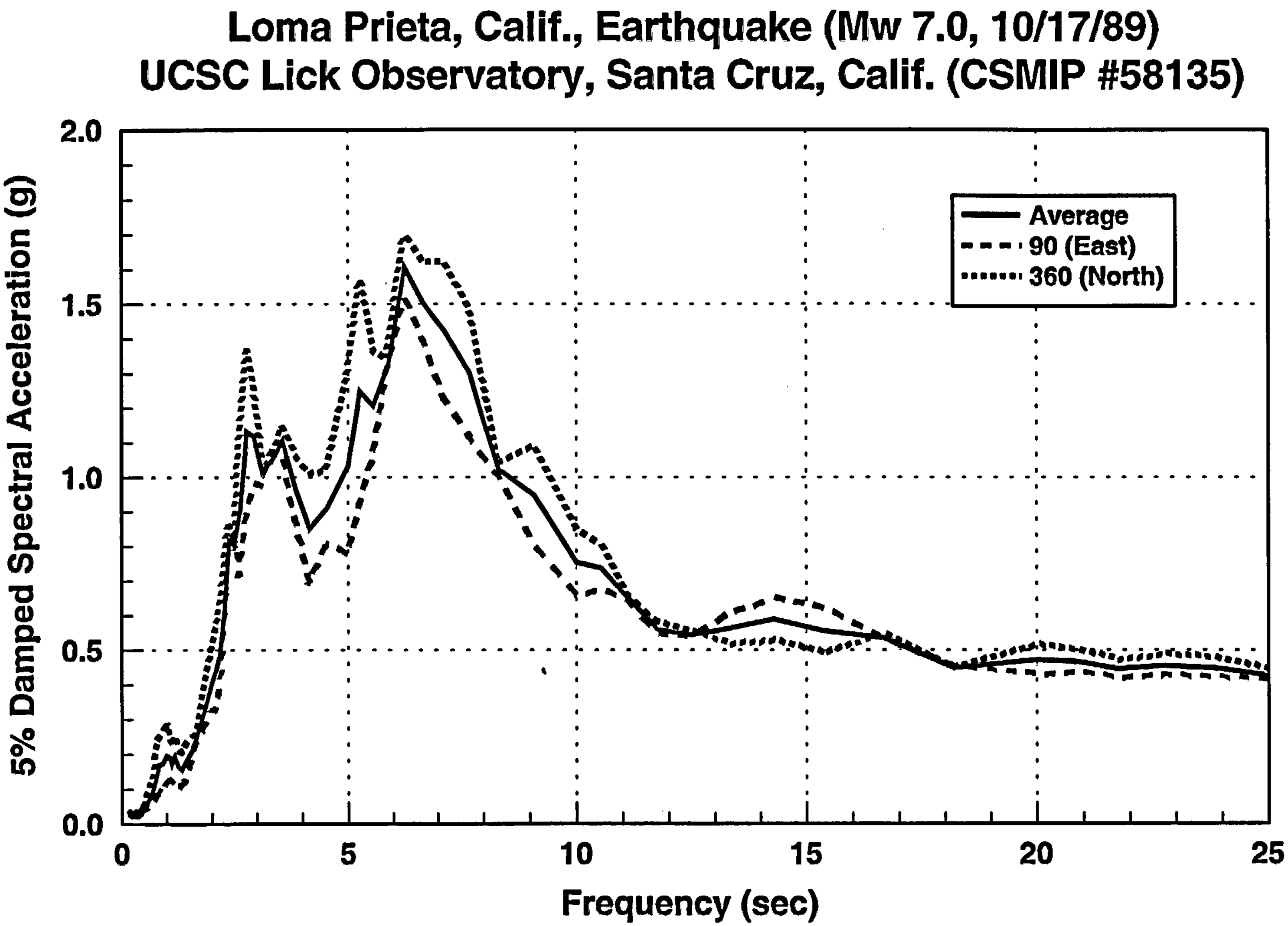

Loma Prieta, Calif., Earthquake (Mw 7.0, 10/17/89)
UCSC Central Campus, Santa Cruz, Calif.
5% Damped Spectral Acceleration (g)
2.0
1.5
1.0
0.5
0.0
0
5
10
15
20
25
Frequency (sec)
Recommended

Figure A-21



Loma Prieta, Calif., Earthquake (Mw 7.0, 10/17/89)
UCSC Lick Observatory, Santa Cruz, Calif. (CSMIP #58135)
5% Damped Spectral Acceleration (g)
2.0
1.5
1.0
0.5
0.0
0
5
10
15
20
25
Frequency (sec)
Average
90 (East)
360 (North)

Figure A-22

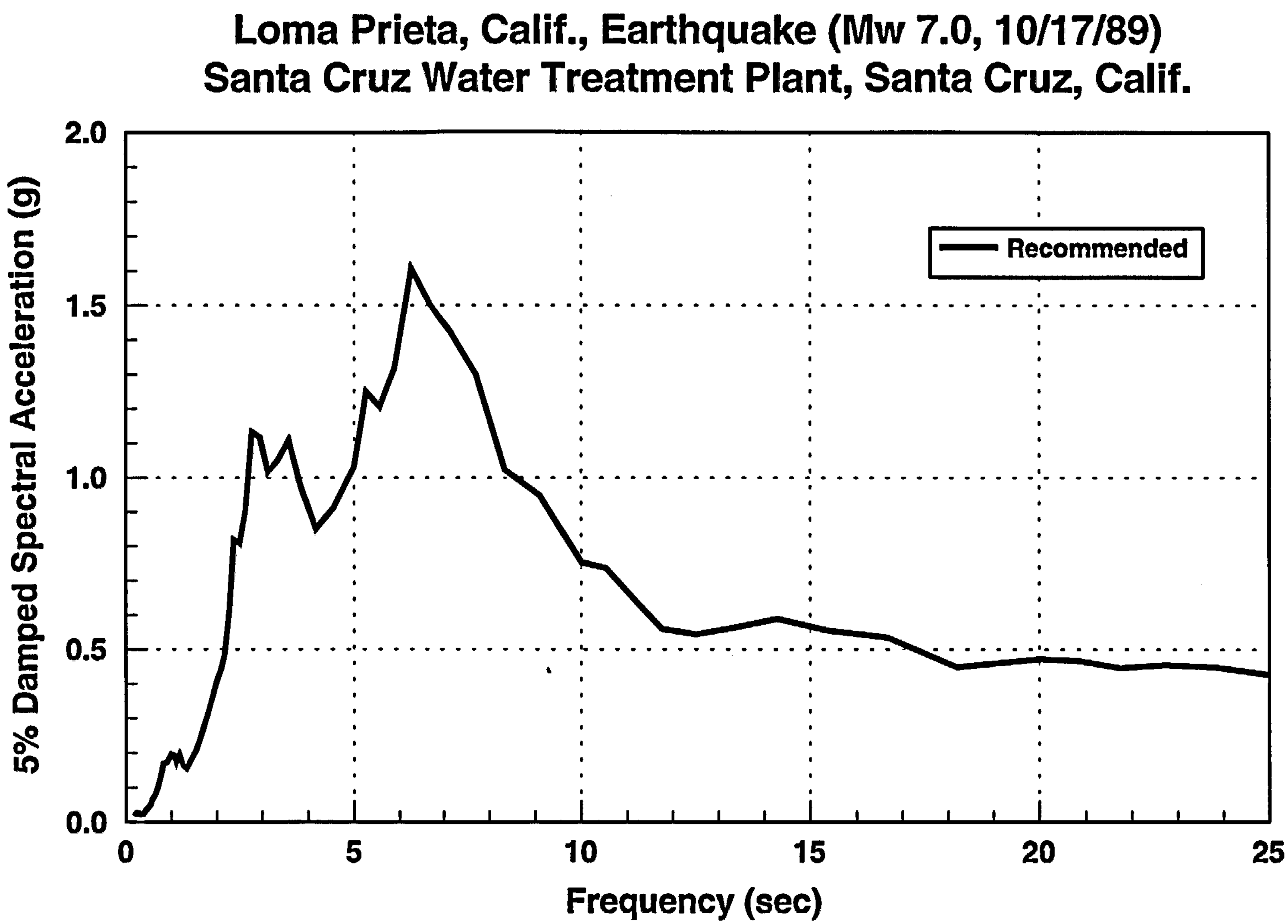

Loma Prieta, Calif., Earthquake (Mw 7.0, 10/17/89)
Santa Cruz Water Treatment Plant, Santa Cruz, Calif.
5% Damped Spectral Acceleration (g)
2.0
1.5
1.0
0.5
0.0
0
5
10
15
20
25
Frequency (sec)
Recommended

Figure A-23

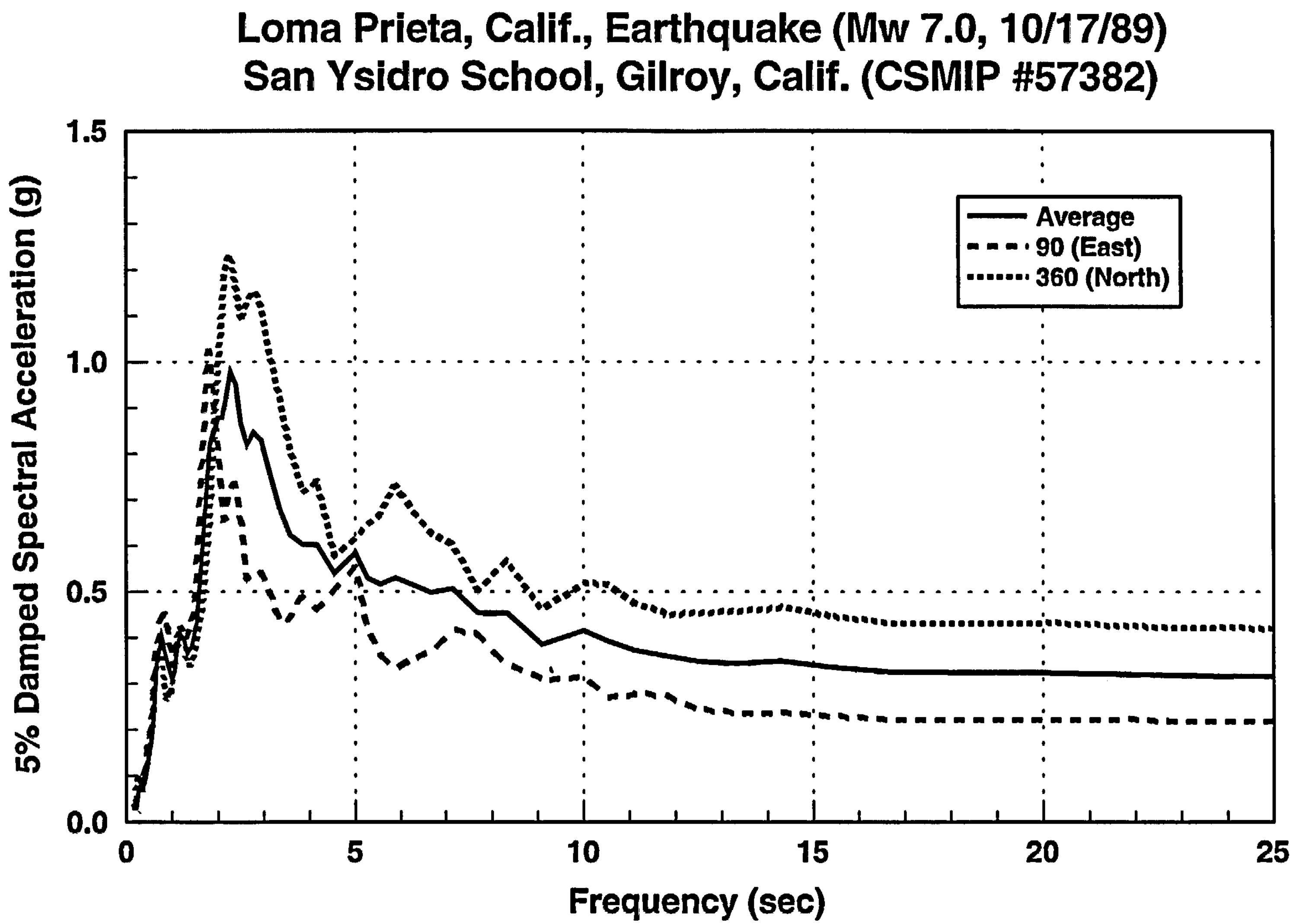

Loma Prieta, Calif., Earthquake (Mw 7.0, 10/17/89)
San Ysidro School, Gilroy, Calif. (CSMIP #57382)
5% Damped Spectral Acceleration (g)
1.5
1.0
0.5
0.0
0
5
10
15
20
25
Frequency (sec)
Average
90 (East)
360 (North)

Figure A-24

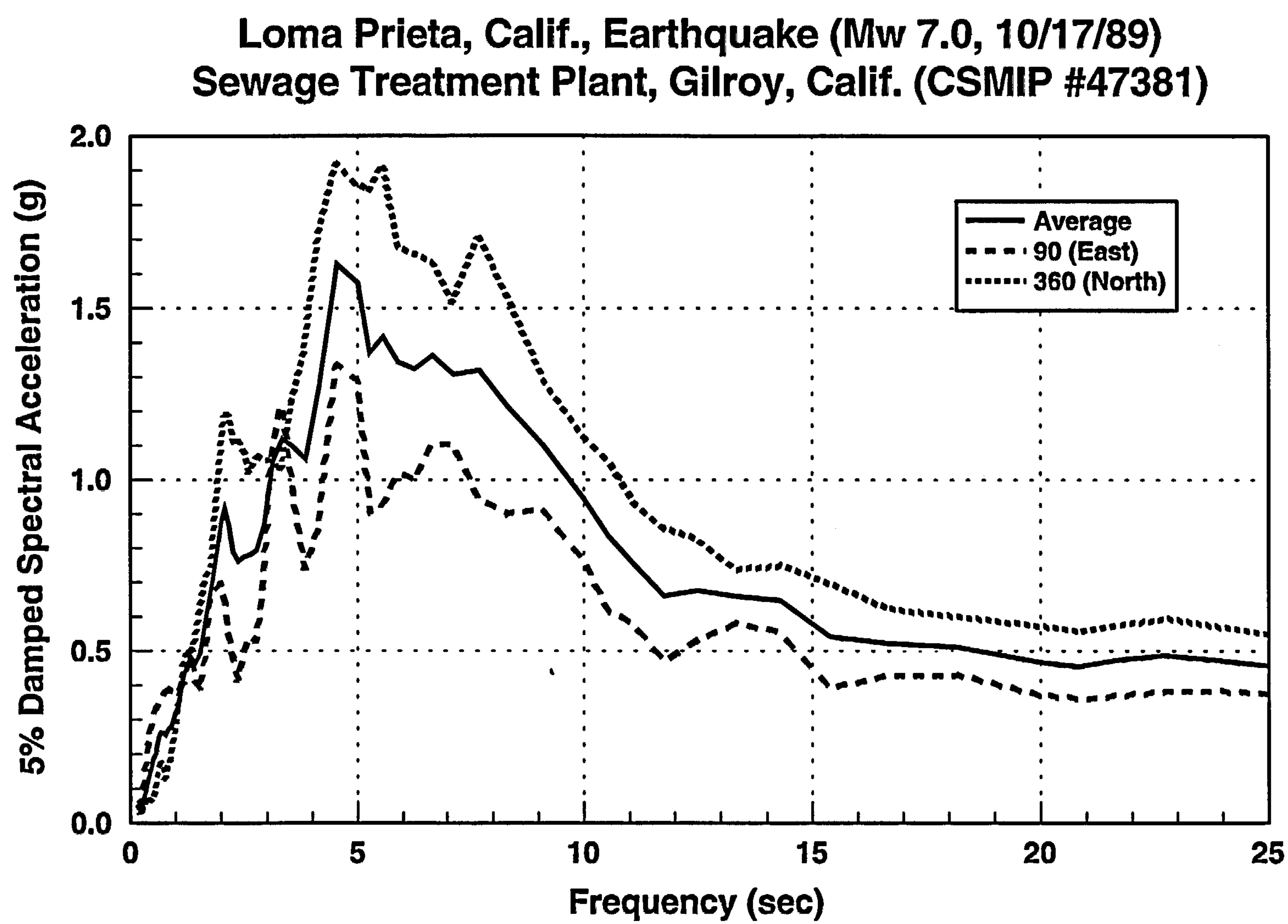

Loma Prieta, Calif., Earthquake (Mw 7.0, 10/17/89)
Sewage Treatment Plant, Gilroy, Calif. (CSMIP #47381)
5% Damped Spectral Acceleration (g)
Frequency (sec)
Average
90 (East)
360 (North)
0.0
0.5
1.0
1.5
2.0
0
5
10
15
20
25

Figure A-25

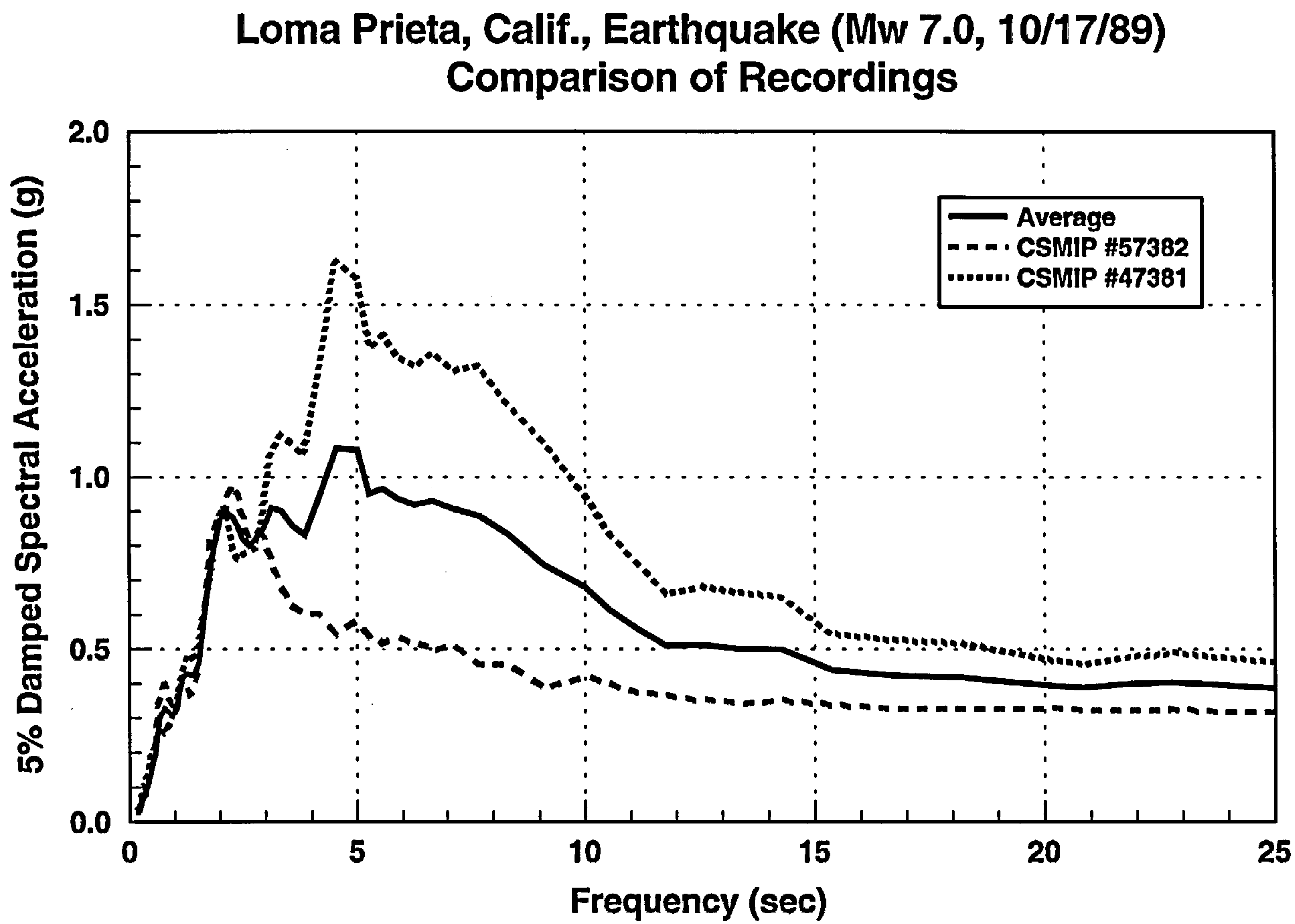

Loma Prieta, Calif., Earthquake (Mw 7.0, 10/17/89)
Comparison of Recordings
5% Damped Spectral Acceleration (g)
Frequency (sec)
Average
CSMIP #57382
CSMIP #47381
0.0
0.5
1.0
1.5
2.0
0
5
10
15
20
25

Figure A-26

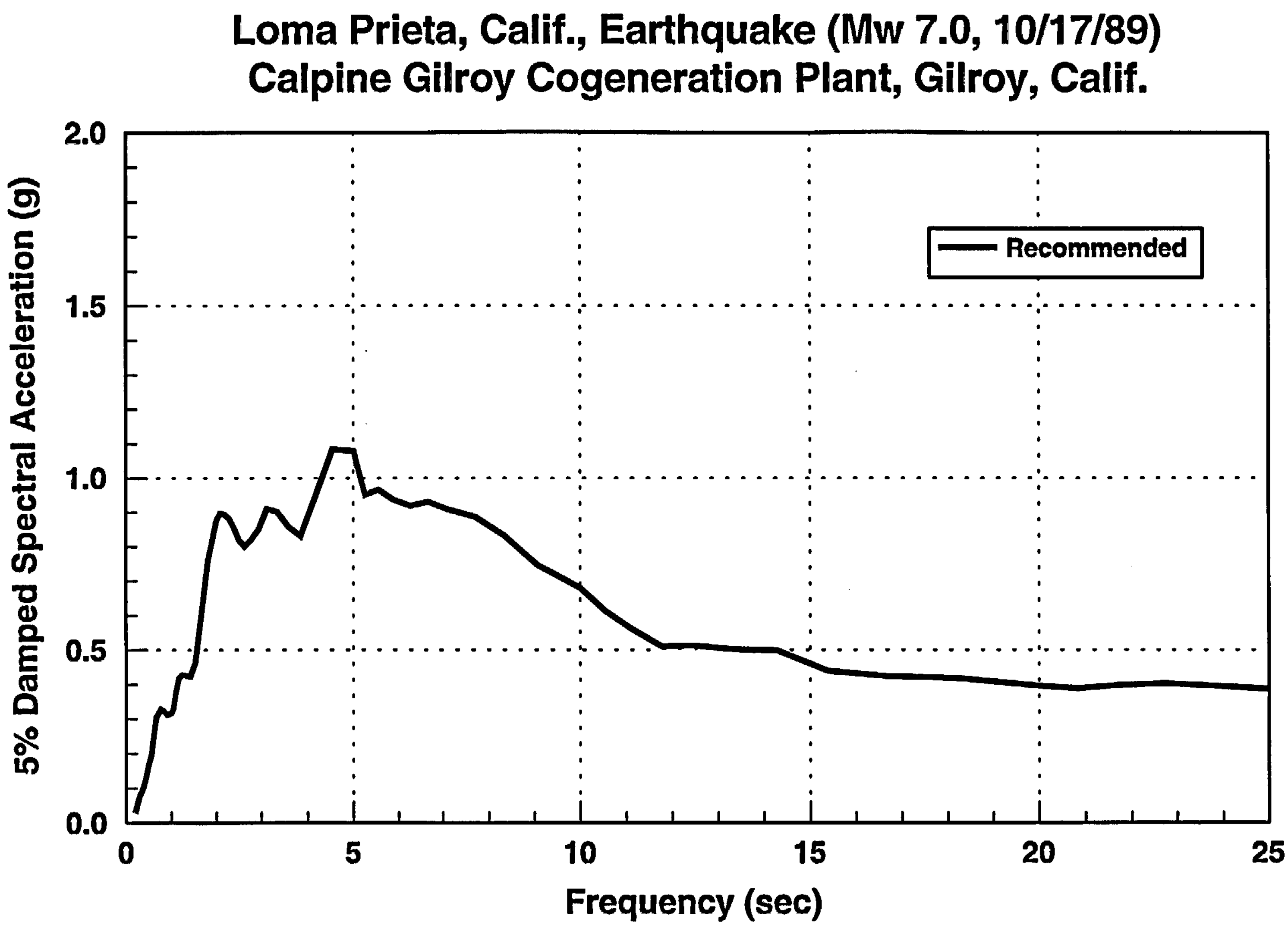

Loma Prieta, Calif., Earthquake (Mw 7.0, 10/17/89)
Calpine Gilroy Cogeneration Plant, Gilroy, Calif.
Recommended
5% Damped Spectral Acceleration (g)
Frequency (sec)
0.0
0.5
1.0
1.5
2.0
0
5
10
15
20
25

Figure A-27

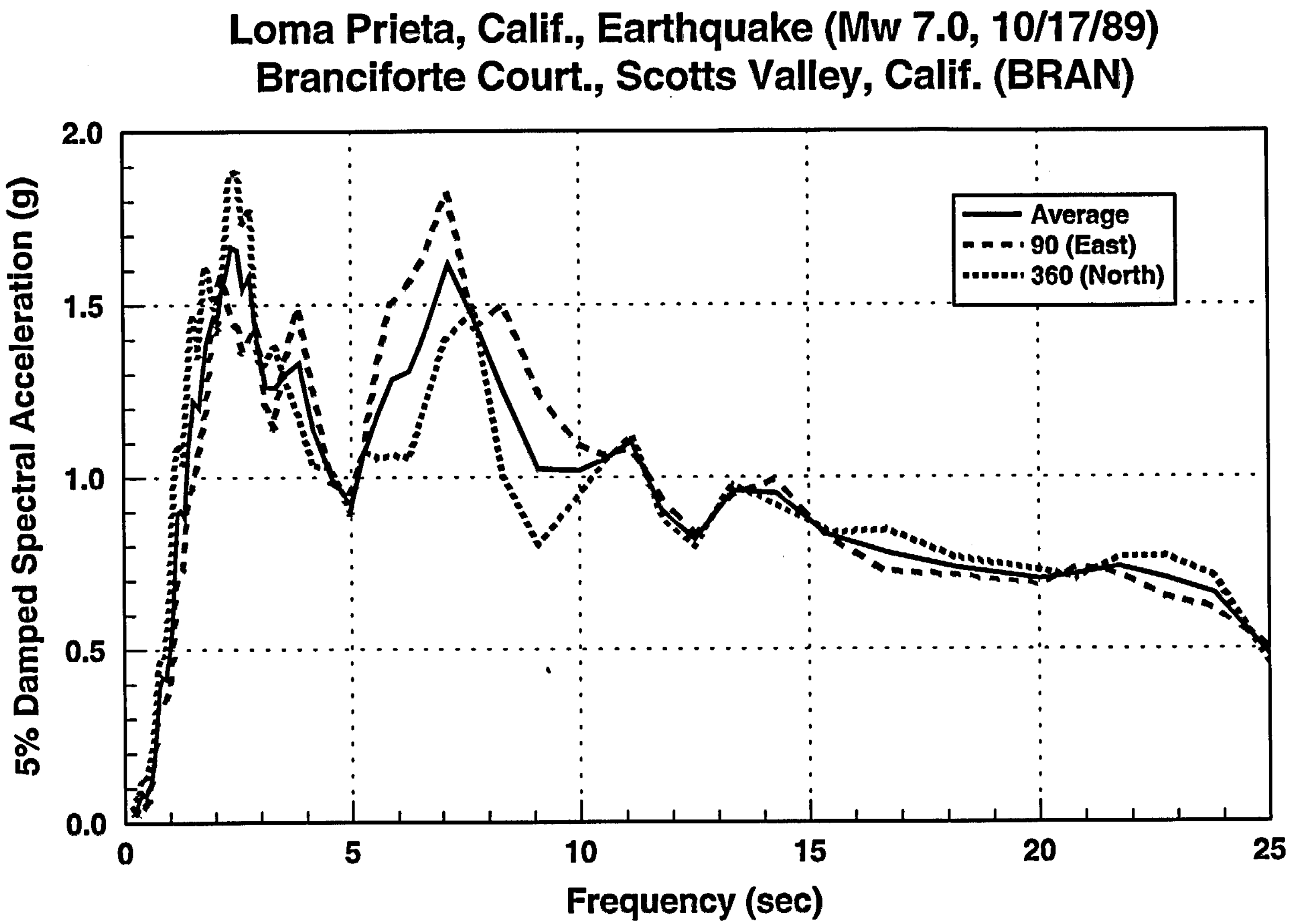
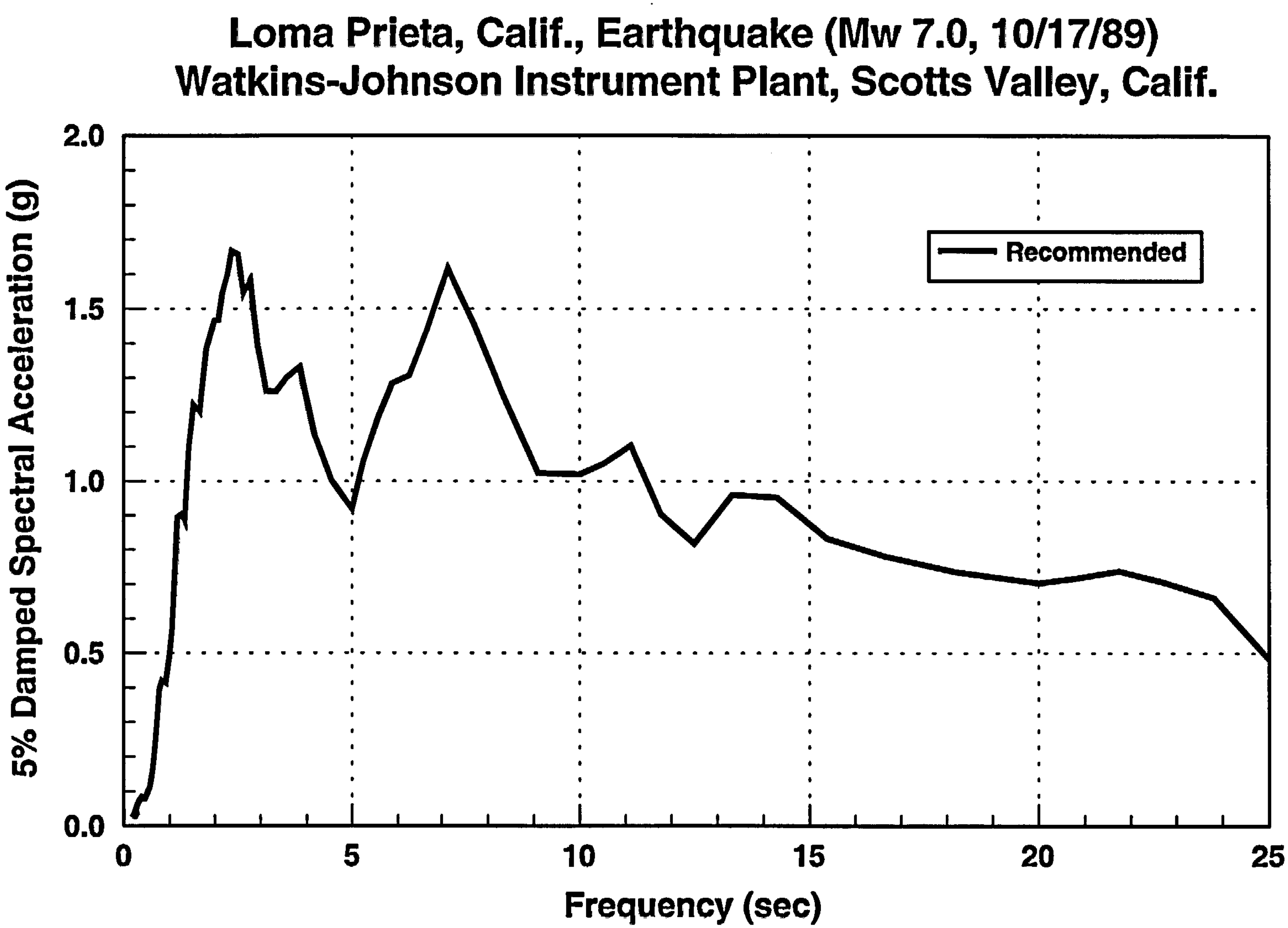

Loma Prieta, Calif., Earthquake (Mw 7.0, 10/17/89)
Branciforte Court., Scotts Valley, Calif. (BRAN)
5% Damped Spectral Acceleration (g)
2.0
1.5
1.0
0.5
0.0
0
5
10
15
20
25
Frequency (sec)
Average
90 (East)
360 (North)

Figure A-28



Loma Prieta, Calif., Earthquake (Mw 7.0, 10/17/89)
Watkins-Johnson Instrument Plant, Scotts Valley, Calif.
5% Damped Spectral Acceleration (g)
2.0
1.5
1.0
0.5
0.0
0
5
10
15
20
25
Frequency (sec)
Recommended

Figure A-29