SECTION 5.0 DEVELOPMENT OF SITE-SPECIFIC GROUND MOTIONS

5.1 GENERAL

This section documents the development of the two earthquake ground motions used for the seismic evaluation of the Main Dam: one represents the ground motion associated with the Maximum Design Earthquake (MDE) and the other is a ground motion associated with the San Andreas Fault System. These ground motions were developed in terms of response spectral values and acceleration time histories compatible with the specified response spectral values.

5.2 POTENTIAL SEISMIC SOURCES AND BACKGROUND INFORMATION

Camanche Reservoir is located within the westernmost foothills of the Sierra Nevada, at the east margin of the Central Valley. Figure 5-1 shows the seismic source map of the site region. As can be seen on this figure, the potential seismic source closest to the reservoir site is the Foothills Fault System. The other seismic sources that might potentially affect the seismic shaking at the site are the Coast Range – Great Valley Fault System and the San Andreas Fault System, both west of the reservoir site. Seismogenic sources near the site are addressed in the review of the regional seismicity contained in Appendix F.

Figure 5-2 shows details on the local seismic sources near the site and the locations of the Main Dam and six dikes. As shown on this figure, the Ione Fault of the Foothills Fault System is the closest to the site.

Table 5-1 summarizes the main characteristics of the regional and local potential seismic sources shown on Figures 5-1 and 5-2. The Foothills Fault System shown on Figure 5-2 is a oblique/normal fault system, with a low slip rate of 0.05 mm/year and an estimated maximum moment magnitude of 6-1/2 for the whole system. However, for conservatism, the Ione Fault shown on Figure 5-2 (that is dipping 75 degrees down to the west and the Main Dam) was used to estimate the shortest distance between the dam site and the seismic source associated with the Foothills Fault System; i.e., about 8.4 miles (or 13.5 km).

Figure 5-3 shows an idealized maximum cross-section of the Main Dam. The foundation rock beneath the embankment is composed of Tertiary-aged sedimentary rocks of the Mehrten, Valley Springs, and Ione formations; these formations are underlain by Cretaceous and Jurassic-aged basement rock of the Sierra Nevada bedrock complex. The foundation rock for the six dikes is similar to those for the Main Dam. The design ground motions were developed at the top of the hypothetical outcrop of the foundation rock (zone 9 on Figure 5-3) beneath the Main Dam as outcrop ground motions.

5.3 NEXT GENERATION ATTENUATION RELATIONSHIPS AND EARTHQUAKE GROUND MOTIONS

An arithmetic average of the five Next Generation Attenuation (NGA) relationships was used to develop design response spectral values for the site (Abrahamson and Silva, 2008; Boore and Atkinson, 2008; Campbell and Bozorgnia, 2008; Chiou and Youngs, 2008; and Idriss, 2008). The NGA relationships are considered much more “scientifically sound” than the earlier attenuation relationships both in terms of the quantity and quality of their ground motion database and the methodologies and parameters reflected in their relationships.

In using the NGA relationships a number of parameters need to be specified. These parameters include the style of faulting, maximum magnitude, and distance to each fault listed in Table 5-1.

Required parameters associated with the site subsurface conditions include: (1) shear-wave velocity (V_{s-30}) within the upper 30 m (100 ft) of the foundation rock (about 0.76 km/sec or 2,500 ft/sec for the Main Dam site), (2) depth to V_s= 1 km/sec or 3,300 ft/sec foundation material (about 0.03 km or 100 ft for the site), and (3) depth to V_s= 2.5 km/sec (8,200 ft/sec) foundation material beneath the dam (about 0.6 km or 2,000 ft for the site). The development of these parameters is summarized in Enclosure 1 of Appendix G.

The values of the parameters required in the NGA relationships and that were used for the Foothills Fault System and the San Andreas Fault System are listed below as examples.

Parameter	Foothills Fault System	San Andreas Fault System
Style of Faulting	Normal/Oblique	Strike Slip
Moment magnitude	6.5	7.9
Dip Angle	75 degrees to the West	90 degrees
Depth to top of rupture	0 km	0 km
Depth to bottom of rupture	12.4 km	13 km
Closest Rupture distance	13.5 km	140 km
Joyner-Boore distance	10.8 km	140 km
Horizontal distance from top edge of rupture	14 km	140 km
Shear wave velocity, V_{s-30}	760 m/s (2,500 fps)	760 m/s (2,500 fps)
Depth to 1 km/s velocity	0.03 km	0.03 km
Depth to 2.5 km/s velocity	0.6 km	0.6 km

Table 5-1 provides estimates of 84th percentile peak horizontal ground acceleration (PGA), 84th percentile peak ground velocity (PGV), and median and 84th percentile Arias intensity using the NGA relationships. These PGA and PGV values correspond to arithmetic averages of results using the five NGA relationships. For the Arias intensity values, results obtained from the Travasarou, Bray, and Abrahamson (2002) and Watson-Lamprey and Abrahamson (2006) attenuation relationships are listed individually. The relationship by Watson-Lamprey and Abrahamson is preferred because the shaking level is reflected in the relationship.

Based on the summary results presented in Table 5-1 and other results, the Foothill Fault System appears to be the dominant seismic source affecting the earthquake shaking at the dam site; however, the slip rate for this fault system is very low at less than 0.05 mm/year. Using the state of California Division of Safety of Dams (DSOD) consequence hazard matrix (Fraser and Howard, 2002) shown in Table 5-2, the 50th to 84th percentile response spectral values could be used for the Foothills Fault System. The District decided to use the 84th percentile response spectral values in the seismic safety evaluation because of the severity of the consequences of dam failure on loss of life and because they consider the uninterrupted service of the Camanche Reservoir facility to be critical to their operations.

The peak ground motion values of the Foothills Fault System shown in Table 5-1 are generally much higher than the others; therefore, the Foothills Fault System was selected as the source of the MDE. However, our study also considered the San Andreas Fault System as a design earthquake source for further evaluation and comparison, because large earthquake magnitudes are associated with this fault.

5.4 SPECTRAL VALUES OF DESIGN AND MAXIMUM DESIGN GROUND MOTIONS

Figure 5-2 shows the longitudinal axis of the Main Dam being sub-parallel to the direction of the Ione Fault. Therefore, design ground motion response spectral values in the transverse direction of the Main Dam are somewhat conservatively selected to be those corresponding to the fault-normal (FN) response spectral values.

The response spectral values corresponding to the FN direction of the Foothills Fault System were obtained using the five NGA relationships. However, it should be noted also that, for a normal faulting system, Abrahamson (2009) recommends a modified version of the hanging-wall tapering model rather than the one presented in the original Abrahamson and Silva (2008) attenuation relationship. The modified tapering model has full directivity effects for distances from the source of 30 km or less, zero directivity effect for distances greater than 60 km, and a linear decrease in directivity effects for distances between 30 and 60 km. As can be inferred from Table 5-1, the directivity effects apply only to the Foothills Fault System; other seismic sources are too far from the dam site.

A consensus has not been developed on how the effects of directivity should be reflected in spectral values of the NGA relationships as of late 2008 (Abrahamson, 2009). Consequently, we made adjustments to the spectral values for directivity effects using a procedure suggested by Fraser and Howard (2002), which is based on Somerville and others (1997) and Abrahamson (2000); the procedure used, as applied to the Foothills Fault System and the dam site, is considered to result in a conservative reflection of the directivity effects for the site.

Figure 5-4 shows the FN response spectral values representing the 84th percentile values obtained from the five NGA relationships and their arithmetic average associated with the Foothills Fault System; the arithmetic average is considered to reflect a portion of the epistemic uncertainty in the NGA relationships. Figure 5-5 shows the resulting FN spectral values considered to represent the MDE response spectrum. These MDE spectral values are listed in Table 5-3.

Because a large earthquake magnitude is associated with the San Andreas Fault System, its impact on the seismic response of the dam is of interest. Figure 5-6 shows the 84th percentile response spectral values obtained from the five NGA relationships and their arithmetic average associated with the San Andreas Fault System. Figure 5-7 shows the resulting San Andreas spectral values. These San Andreas spectral values are listed in Table 5-4.

The 84th percentile response spectral values corresponding to the FN component of the Foothills Fault System are shown on Figure 5-8 along with the 84th percentile response spectral values (corresponding to arithmetic averages of the five NGA relationships) for all the other seismic sources listed in Table 5-1. As can be seen on this figure, the response spectral values associated with the Foothills Fault System are significantly higher than the others for the entire range of periods considered.

Figure 5-9 shows the same information as Figure 5-8, but in terms of ratio values, where the 84th percentile response spectral values for each seismic source considered on Figure 5-8 are divided by the corresponding values for the Foothills Fault System. As can be seen on Figure 5-9, the 84th percentile PGA values from the other sources are about 20 percent of the 84th percentile PGA associated with the Foothills Fault System. The only exceptions are the Coast Range – Great Valley Fault System ($M_w = 6.8$) at about 30 percent and the San Andreas Fault System ($M_w = 7.9$) at about 25 percent. When these ratio values are adjusted for the "duration effects" on liquefaction triggering (Idriss and Boulanger, 2008), they become about 25 percent and 50 percent, for the Coast Range – Great Valley Fault System and the San Andreas Fault System, respectively. Therefore, the duration adjusted PGA values for the Coast Range – Great Valley Fault System and the San Andreas Fault System are about 0.08 and 0.14g, respectively; i.e., still far below the 84th percentile PGA value for the Foothills Fault System at 0.29g. These values are probably too low to trigger liquefaction at the site.

Furthermore, at the fundamental period of the Main Dam (at the maximum cross section) of about 0.6 second, Figure 5-9 indicates that the response spectral values associated with the Coast Range – Great Valley Fault System and the San Andreas Fault System are about 35 percent of that associated with the Foothills Fault System. Therefore, the response of the maximum cross section of the dam under the postulated seismic shaking from the Coast Range – Great Valley Fault System or the San Andreas Fault System is likely to be significantly less than that from the FN seismic shaking from the Foothills Fault System, even when one considers the effects of durations.

Finally, as can be seen on Figure 5-9, the largest spectral ratio associated with the San Andreas Fault System is about 0.5 (or 50 percent) at a period of about 2 seconds. The period of 2 seconds is considered too large to significantly affect the seismic response of the dam with a fundamental period of about 0.6 second.

The District, in consultation with DSOD, decided to consider an 84th percentile shaking from the San Andreas Fault System as part of the seismic evaluation of the Main Dam in order to evaluate the seismic effects of ground motion that might be perceived as more likely to occur at the site than the highly unlikely event postulated for the Foothills Fault System, that is represented by the 84th percentile FN spectral values developed herein. This issue is further addressed in Section 5.5.

In summary, the FN 84th percentile response spectral values based on the arithmetic average of the five NGA relationships for the Foothills Fault System are considered to represent the MDE ground motions for the main Dam site, and the 84th percentile response spectral values based on the arithmetic average of the five NGA relationships for the San Andreas Fault System are considered to represent a San Andreas ground motion for the dam site to be used in a parametric way.

5.5 PROBABILISTIC SEISMIC HAZARD ANALYSIS (PSHA)

We completed a probabilistic seismic hazard analysis (PSHA) using the NGA relationships for the site and generally following the California Geological Survey database for seismic source characterization. The results of the PSHA are summarized on Figure 5-10 and 5-11 in terms of PGA and response spectral acceleration at 0.5 second, respectively, versus annual frequency of exceedance (and its inverse, average return period or ARP). The period of 0.5 second is the period closest to the estimated fundamental period of the maximum cross section of the dam (i.e., about 0.6 second) where non-interpolated values from the NGA relationships are available. Figure 5-12 shows the PGA results shown on Figure 5-10 weighted with respect to a moment magnitude 6.5, using the magnitude weighting relationship by Idriss and Boulanger (2008) for triggering of liquefaction.

On Figures 5-10 to 5-12, the response spectral value associated with the MDE response spectrum is identified on the total hazard curve, with a horizontal dashed line to indicate the associated ARP and a vertical dashed line to indicate the contribution of various seismic sources based on the PSHA results.

As shown on Figures 5-10 and 5-11, the ARP of the MDE PGA is about 38,000 years and the ARP of the MDE spectral acceleration at a period of 0.5 second is about 24,000 years. Figure 5-12 indicates that the ARP of the magnitude-weighted MDE remains at about 38,000 years. These ARP values are very long and indicate the very conservative nature of the MDE proposed for the site as compared to many other dams in California where the ARP values are typically about a few thousand years or less (Fraser and Burns, 2004).

It should be noted that the vertical dashed lines on Figures 5-10 through 5-12 indicate that the Foothills Fault System is dominant at the dam site even for the spectral value near the fundamental period of the maximum cross section (Figure 5-11). Therefore, although an earthquake shaking from a San Andreas event may be more likely at the site than one from the Foothills Fault System, the adopted MDE spectral values would unlikely be associated with seismic sources other than those from the Foothills Fault System. This appears to be the case even at the estimated fundamental period of the maximum cross section. The effects of longer duration associated with the San Andreas Fault System do not change this conclusion.

5.6 ACCELERATION TIME HISTORIES TO BE ADJUSTED FOR USE IN SEISMIC ANALYSES

Based on the MDE response spectral values shown on Figure 5-6 and listed in Table 5-3 for the Foothills Fault System, six seed acceleration-time histories were considered for potential use in developing spectrum-compatible acceleration time histories for the seismic response and deformation analyses. However, as discussed in Enclosure 2 of Appendix G, only three of these seed time histories were selected to develop three spectrum-compatible MDE acceleration time histories for the seismic response and deformation analyses of the Main Dam: the 1989 Loma Prieta, the 1994 Northridge and the 1995 Kobe (Nishi-Akashi station). The characteristics of these time histories are summarized in Table 5-5a. Also shown in this table are the M_w, maximum velocity, maximum displacement, and the Arias intensity values associated with these candidate recorded acceleration time histories. The acceleration, velocity, and displacement-time histories for the above seed recordings are shown on Figures 5-13 to 5-15, along with their Arias intensity.

Based on the San Andreas response spectral values shown on Figure 5-7 and listed in Table 5-4 for the San Andreas Fault System, one seed acceleration-time history was selected for use in developing spectrum-compatible San Andreas acceleration time history for the seismic response and deformation analyses of the dam as summarized in Table 5-5b. The San Andreas seed time history is from the 2002 Denali earthquake. Also shown in Table 5-5b are the M_w, maximum velocity, maximum displacement, and the Aries intensity values associated with this seed recorded acceleration time history. The acceleration, velocity, and displacement-time histories for the seed recording and the Arias intensity of the Denali motion are shown on Figure 5-16.

5.7 ADJUSTED TIME HISTORIES

The adjusted MDE time histories are shown as follows:

- Figure 5-17 shows the adjusted MDE time history based on the Loma Prieta motion in terms of acceleration, velocity, and displacement time histories and a comparison of the response spectral values with the MDE response spectral values. Figure 5-18 shows the same ground motion in terms of acceleration time history, Arias intensity, and Newmark displacement. On the Arias intensity plot, the median and the 84^{th} percentile Arias intensity values correspond to the postulated MDE motion using the Travasarou and others (2002) relationship and the Watson-Lamprey and Abrahamson (2006) relationship.
- Figures 5-19 and 5-20 show the same information as Figures 5-17 and 5-18, but for the adjusted time history based on the Northridge motion.
- Similarly, Figures 5-21 and 5-22 show the same information as Figures 5-17 and 5-18, but for the adjusted time history based on the Kobe motion.

It should be noted that the Arias intensity values of the MDE ground motions in the range of 0.7 m/s to 1.4 m/s (i.e., the 47 percentile and 98 percentile values discussed in Enclosure 2 of Appendix G) are consistent with the median and 84^{th} percentile Arias intensity values given the 84th percentile spectral values (i.e., a median Arias intensity value of 0.7 m/s and an 84th percentile Arias intensity value of 1.0 m/s using the Watson-Lamprey and Abrahamson relationship) shown on Figures 5-18, 5-20, and 5-21.

Figure 5-23 shows the adjusted time history based on the San Andreas motion in terms of acceleration, velocity, and displacement time histories and a comparison of the response spectral values with the MDE response spectral values. Figure 5-24 shows the same ground motion in terms of acceleration time history, Arias intensity, and Newmark displacement.

It should be noted that the Arias intensity value associated with the adjusted San Andreas ground motion is very much larger than the median and the 84^{th} percentile Arias intensity values calculated for this ground motion conditions using either of the Travasarou and others (2002) relationship or the Watson-Lamprey and Abrahamson (2006) relationship.

TABLE 5-1
CHARACTERIZATION AND ASSOCIATED GROUND MOTION PARAMETERS OF SIGNIFICANT FAULTS

Fault Name	Style of Faulting[3]	Maximum Magnitude (Mw)	Slip Rate (mm/yr)	Closest Distance From Site to Fault Rupture[4] (km)	PGA[5] (g) (84^{th} %)	PGV[5] (cm/s) (84^{th} %)	Arias Intensity (m/s)			
							Median		84th Percentile	
							(6)	(7)	(6)	(7)
Foothills Fault System[1]	OBL	6.5	0.05	13.5	0.29	17.8	0.4	0.68	1.2	0.96
Coast Range - Great Valley[2]	RV	6.8	1.5	73	0.10	7.0	0.09	0.11	0.25	0.15
Hunting Creek-Berryessa[1]	SS	7.1	6.0	106	0.05	5.3	0.04	0.06	0.12	0.08
Hayward (all segments)[2]	SS	7.1	9.0	111	0.05	5.1	0.04	0.05	0.11	0.07
Mohawk-Honey Lake Zone[1]	SS	7.3	2.0	117	0.05	6.1	0.04	0.06	0.12	0.09
San Andreas (1906 rupture)[2]	SS	7.9	24.0	140	0.07	9.9	0.05	0.13	0.15	0.18
Bartlett Springs Fault System[1]	SS	7.6	6.0	151	0.05	6.8	0.03	0.06	0.11	0.09
Maacoma-Garberville[1]	SS	7.5	9.0	151	0.05	6.1	0.03	0.05	0.1	0.08

Notes:

(1) Style of faulting, Mw and Slip rate, based on information published by the California Geological Survey - (Cao, et al., 2002)

(2) Style of faulting, Mw and Slip rate, based on Camanche Dam Supporting Technical Information Document by EBMUD & GEI Consultants, Inc. (March 2008)

(3) SS=Strike-Slip, OBL=Oblique, RV=Reverse or Thrust

(4) Based on CGS database

(5) Average 84th percentile value obtained from 5 NGA attenuation relationships: Abrahamson and Silva (2007), Boore and Atkinson (2007), Campbell and Bozorgnia (2007), Chiou and Youngs (2008), and Idriss (2007)

(6) By T. Travasarou, J. Bray, and N. Abrahamson (2002)

(7) By J. Watson-Lamprey and N. Abrahamson (2006)

TABLE 5-2
DSOD CONSEQUENCE-HAZARD MATRIX

	Very High Slip Rate 9 or greater mm/yr	High Slip Rate 8.1 to 1.1 mm/yr	Moderate Slip Rate 1.0 to 0.1 mm/yr	Low Slip Rate Less than 0.1 mm/yr
Extreme Consequence Total Class Weight 31-36	84th	84th	84th	50th to 84th
High Consequence Total Class Weight 19-30	84th	84th	50th to 84th	50th to 84th
Moderate Consequence Total Class Weight 7-18	84th	50th to 84th	50th to 84th	50th
Low Consequence Total Class Weight 0-6	50th	50th	50th	50th

October 4, 2002

Used to Determine the Appropriate Statistical Level of Acceleration for Deterministic Seismic Hazard Analyses

TABLE 5-3

MDE SPECTRAL ORDINATES

FOOTHILLS FAULT SYSTEM FAULT NORMAL - 84TH PERCENTILE

Spectral Damping=5%							
No.	**Period (s)**	**Frequency (Hz)**	**Sa (g)**	**Sv (cm/s)**	**Sv (in/s)**	**Sd (cm)**	**Sd (in)**
1	0.01	100.00	0.292	0.457	0.180	0.001	0.000
2	0.03	33.33	0.320	1.498	0.590	0.007	0.003
3	0.05	20.00	0.386	3.013	1.186	0.024	0.009
4	0.075	13.33	0.498	5.836	2.297	0.070	0.027
5	0.10	10.00	0.599	9.362	3.686	0.149	0.059
6	0.15	6.67	0.718	16.831	6.626	0.402	0.158
7	0.20	5.00	0.743	23.202	9.135	0.739	0.291
8	0.30	3.33	0.629	29.486	11.609	1.408	0.554
9	0.40	2.50	0.529	33.077	13.022	2.106	0.829
10	0.50	2.00	0.439	34.277	13.495	2.728	1.074
11	1.00	1.00	0.248	38.716	15.243	6.162	2.426
12	1.50	0.67	0.167	39.038	15.369	9.320	3.669
13	2.00	0.50	0.121	37.735	14.856	12.012	4.729
14	3.00	0.33	0.076	35.740	14.071	17.065	6.718
15	4.00	0.25	0.055	34.367	13.530	21.879	8.614
16	5.00	0.20	0.043	33.540	13.205	26.690	10.508

Notes:

1. Zero-Period Acceleration (PGA) = 0.29g.
2. Sa = Pseudo-Absolute Spectral Acceleration; Sv = Pseudo-Relative Spectral Velocity; and Sd = Relative Spectral Displacement.
3. Significant figures in above table are provided for computation purposes only and do not necessarily reflect accuracy to those significant figures.

TABLE 5-4

SAN ANDREAS SPECTRAL ORDINATES - 84TH PERCENTILE

Spectral Damping=5%							
No.	**Period (s)**	**Frequency (Hz)**	**Sa (g)**	**Sv (cm/s)**	**Sv (in/s)**	**Sd (cm)**	**Sd (in)**
1	0.01	100.00	0.069	0.108	0.042	0.000	0.000
2	0.03	33.33	0.072	0.339	0.134	0.002	0.001
3	0.05	20.00	0.080	0.621	0.245	0.005	0.002
4	0.075	13.33	0.092	1.073	0.422	0.013	0.005
5	0.10	10.00	0.104	1.630	0.642	0.026	0.010
6	0.15	6.67	0.129	3.022	1.190	0.072	0.028
7	0.20	5.00	0.147	4.593	1.808	0.146	0.058
8	0.30	3.33	0.162	7.599	2.992	0.363	0.143
9	0.40	2.50	0.158	9.884	3.891	0.629	0.248
10	0.50	2.00	0.150	11.692	4.603	0.930	0.366
11	1.00	1.00	0.108	16.879	6.645	2.686	1.058
12	1.50	0.67	0.080	18.779	7.393	4.483	1.765
13	2.00	0.50	0.061	19.085	7.514	6.075	2.392
14	3.00	0.33	0.038	17.873	7.036	8.534	3.360
15	4.00	0.25	0.025	15.645	6.159	9.960	3.921
16	5.00	0.20	0.019	14.616	5.754	11.631	4.579

Notes:

1. Zero-Period Acceleration (PGA) = 0.07g.
2. Sa = Pseudo-Absolute Spectral Acceleration; Sv = Pseudo-Relative Spectral Velocity; and Sd = Relative Spectral Displacement.
3. Significant figures in above table are provided for computation purposes only and do not necessarily reflect accuracy to those significant figures.

TABLE 5-5a

CHARACTERISTICS OF EARTHQUAKE RECORDS SELECTED FOR THE MDE GROUND MOTION

FOOTHILLS FAULT SYSTEM

Earthquake Event	Recording Station	Style of Faulting (1)	Magnitude (Mw)	Closest Distance (km)	NEHRP Site Classification	Highest Usable Period (sec)	Event Date
Loma Prieta	San Jose - Santa Teresa Hills	RV/OBL	6.9	14.7	C	15.8	10/18/89
Northridge	Cataic - Old Ridge Route	RV	6.7	20.7	C	8.3	01/17/94
Kobe	Nishi - Akashi	SS	6.9	7.1	C	8.0	01/16/95

TABLE 5-5b

CHARACTERISTICS OF EARTHQUAKE RECORD SELECTED FOR SAN ANDREAS GROUND MOTION

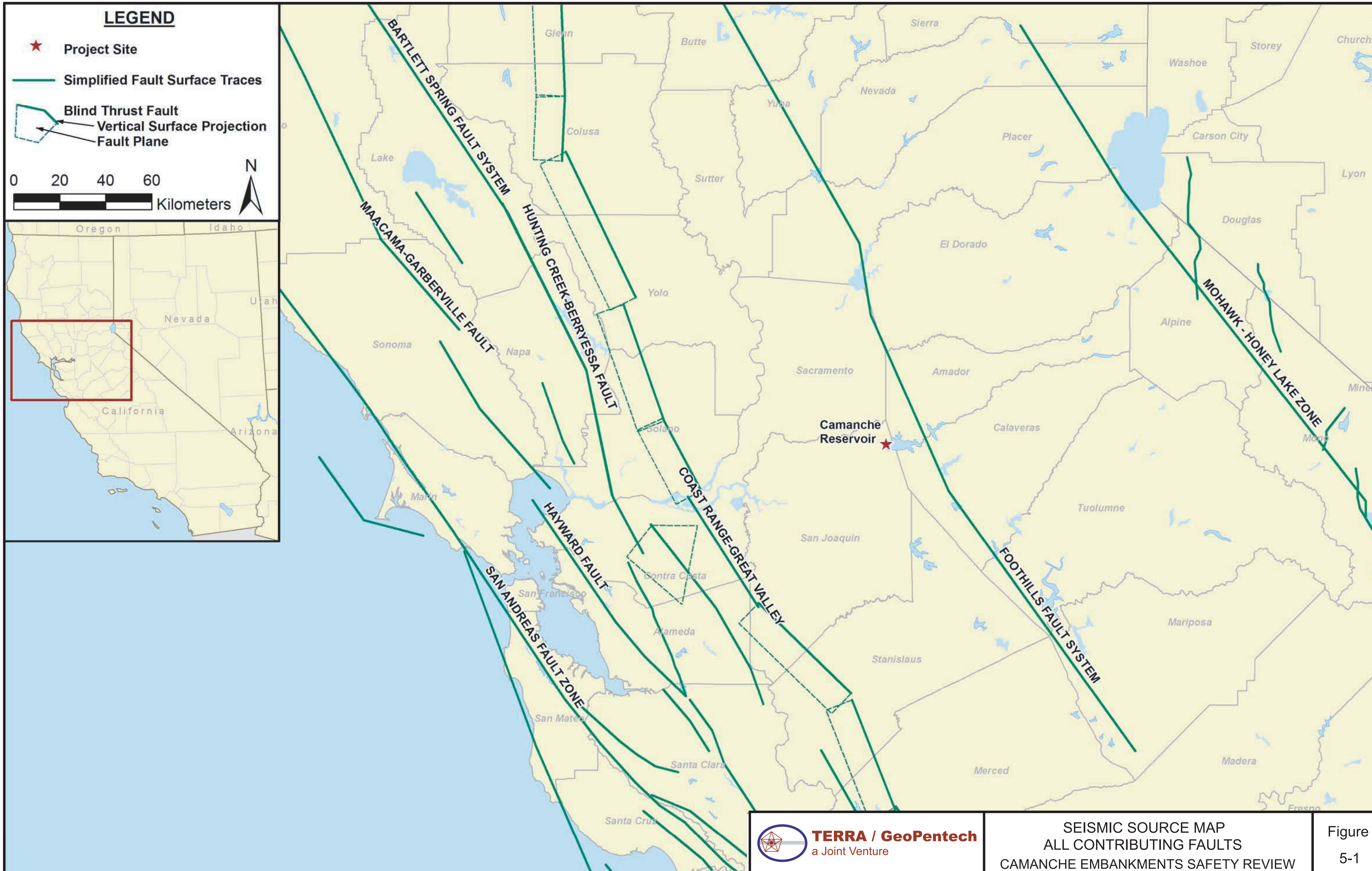
SAN ANDREAS FAULT SYSTEM

Earthquake Event	Recording Station	Style of Faulting (1)	Magnitude (Mw)	Closest Distance (km)	NEHRP Site Classification	Highest Usable Period (sec)	Event Date
Denali	TAPS Pump Station No. 11	SS	7.9	126.4	C	7.7	11/03/02

Notes:

(1) SS=Strike-Slip, OBL=Oblique, RV=Reverse or Thrust

(2) MDE=Maximum Design Earthquake

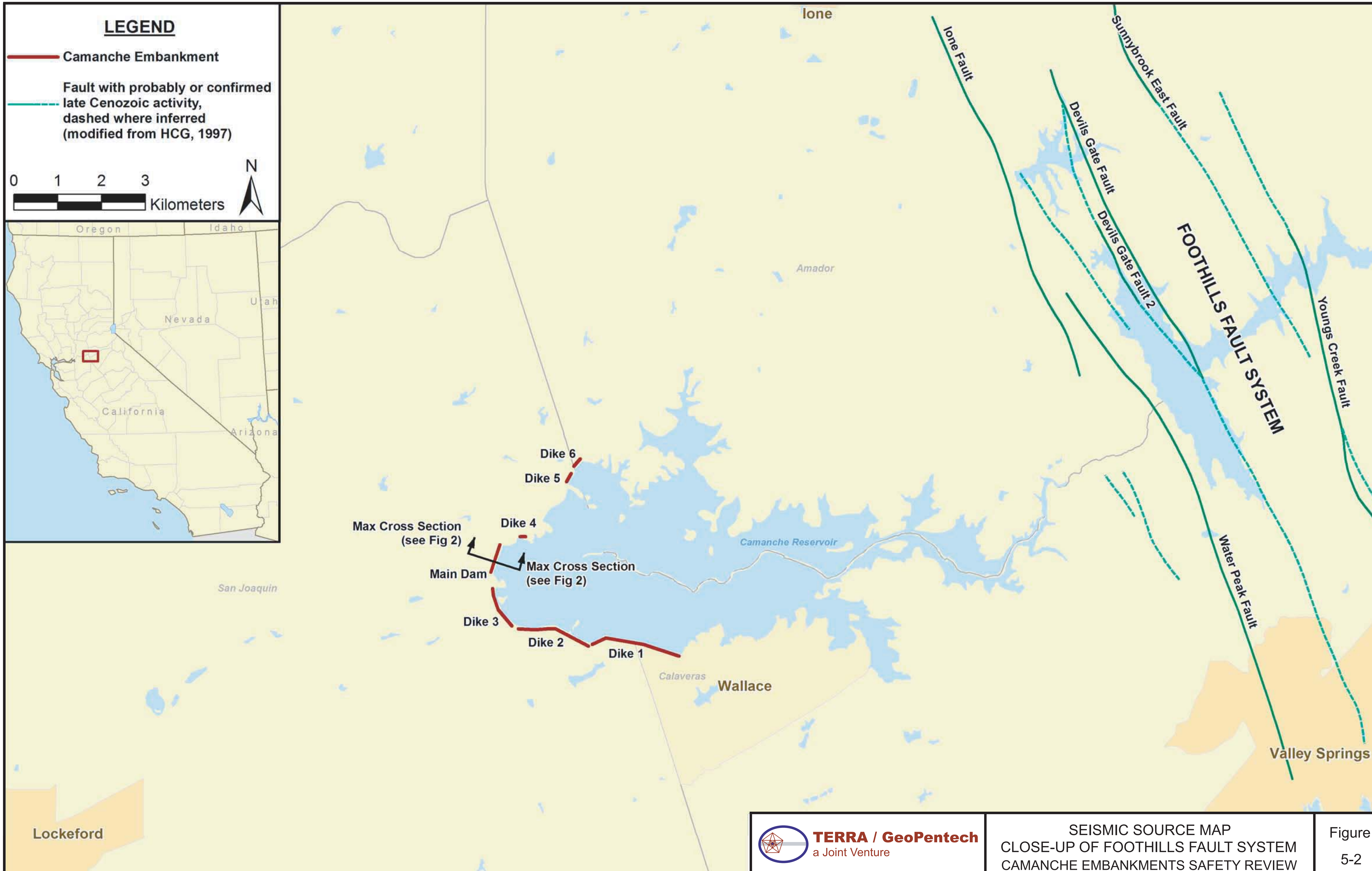


TERRA / GeoPentech
a Joint Venture

SEISMIC SOURCE MAP
ALL CONTRIBUTING FAULTS
CAMANCHE EMBANKMENTS SAFETY REVIEW

Figure 5-1

Rev. 1 02/05/10



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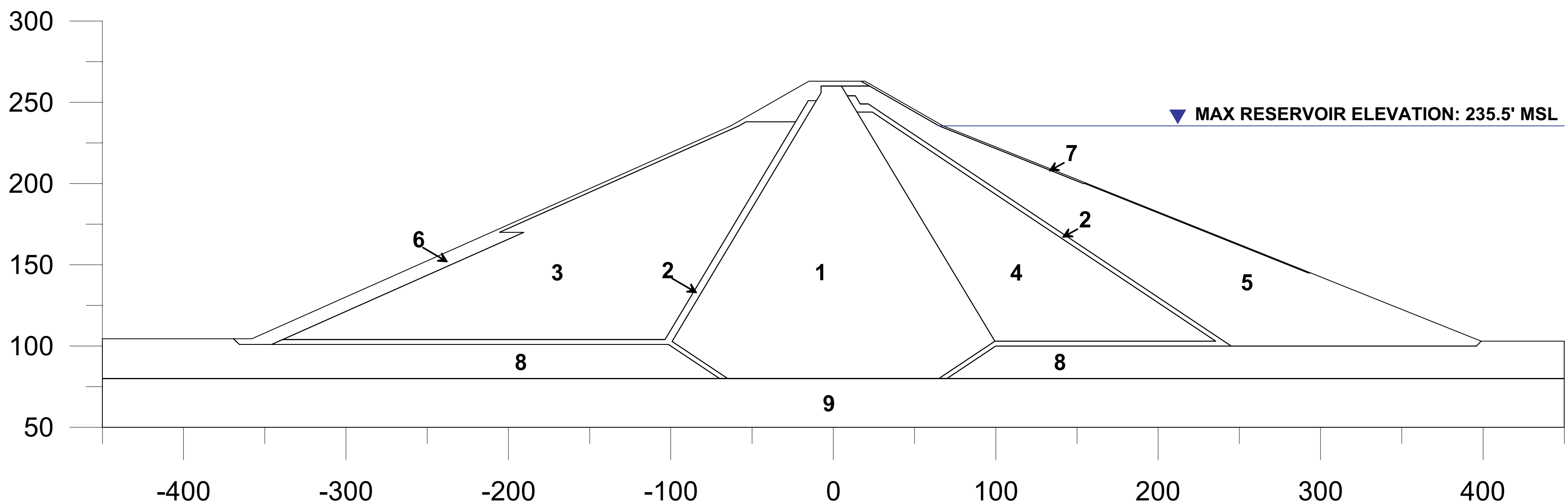
SEISMIC SOURCE MAP
CLOSE-UP OF FOOTHILLS FAULT SYSTEM
CAMANCHE EMBANKMENTS SAFETY REVIEW

Figure 5-2

Rev. 02 02/05/10

Zone	Material
1	Core Material - Impervoius Material from Borrow Area 1, 2, and 2a
2	Drain Material - Processed Sand and Gravel from Borrow Area 3
3	Downstream Shell Material - Sand or Sand and Gravel from Borrow Area 3
4	Upstream Shell Material - Sand or Sand and Gravel from Borrow Area 3
5	Upstream Shell Material - Gravel and Cobbles from Borrow Area 3
6	Downstream Slope Protection - Select Gravel and Cobbles from Borrow Area 3
7	Upstream Slope Protection - Rip-Rap from Quarry
8	Tailings
9	Mehrten Formation Bedrock



Note: Geometry based on Bechtel drawing 4460-G-132, 1961, except grade at downstream toe understood to be 104.5' MSL based on piezometer elevations.

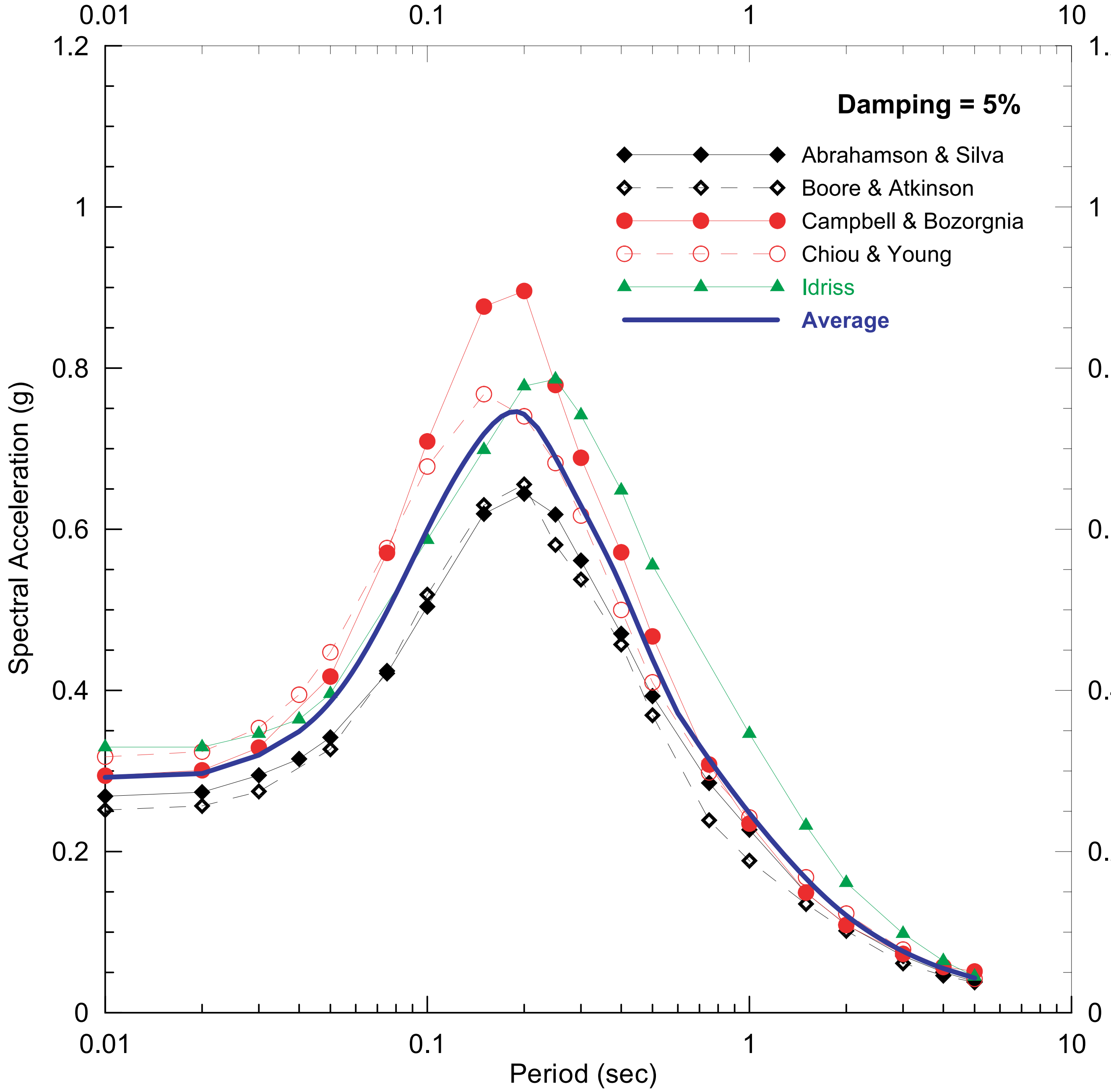
TERRA / GeoPentech
a Joint Venture

MAIN DAM
MAXIMUM CROSS SECTION
CAMANCHE EMBANKMENTS SAFETY REVIEW

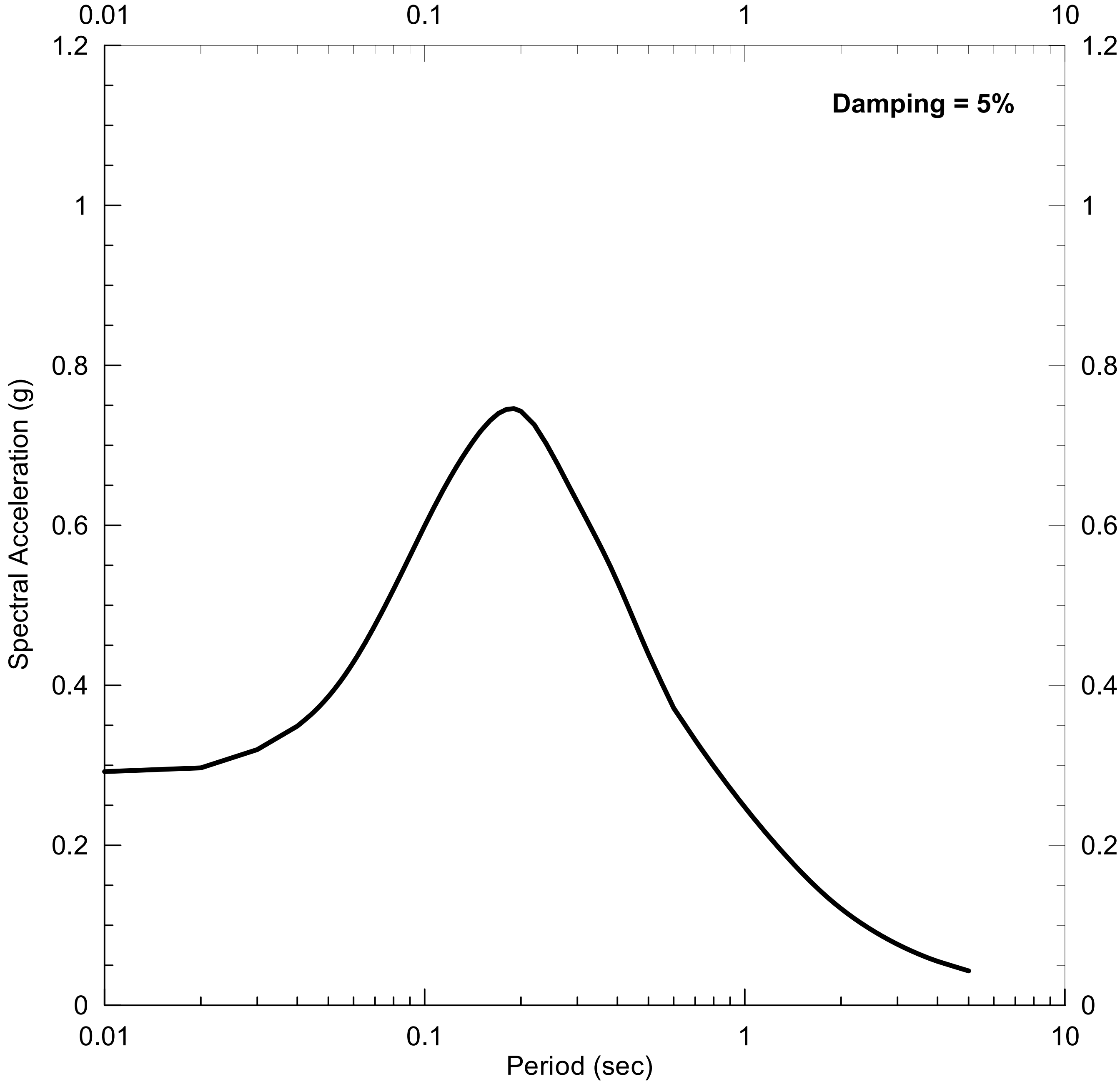
Figure 5-3

Rev. 1 02/05/10

Fault: Foothills Fault System
Magnitude (Mw): 6-1/2
Closest Distance (km): 13.5
Site classification: Rock or Vs = 760 m/s (2,500 fps)
Fault rupture mechanism: Strike-slip/Normal
Fault directivity effect: Abrahamson (2000), Fraser & Howard (2002)



Fault:	Foothills Fault System
Magnitude (Mw):	6-1/2
Closest Distance (km):	13.5
Site classification:	Rock or Vs =760 m/s (2,500 fps)
Fault rupture mechanism:	Strike-slip/Normal
Fault directivity effect:	Abrahamson (2000), Fraser & Howard (2002)



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MDE RESPONSE SPECTRUM

CAMANCHE EMBANKMENTS SAFETY REVIEW

Figure 5-5

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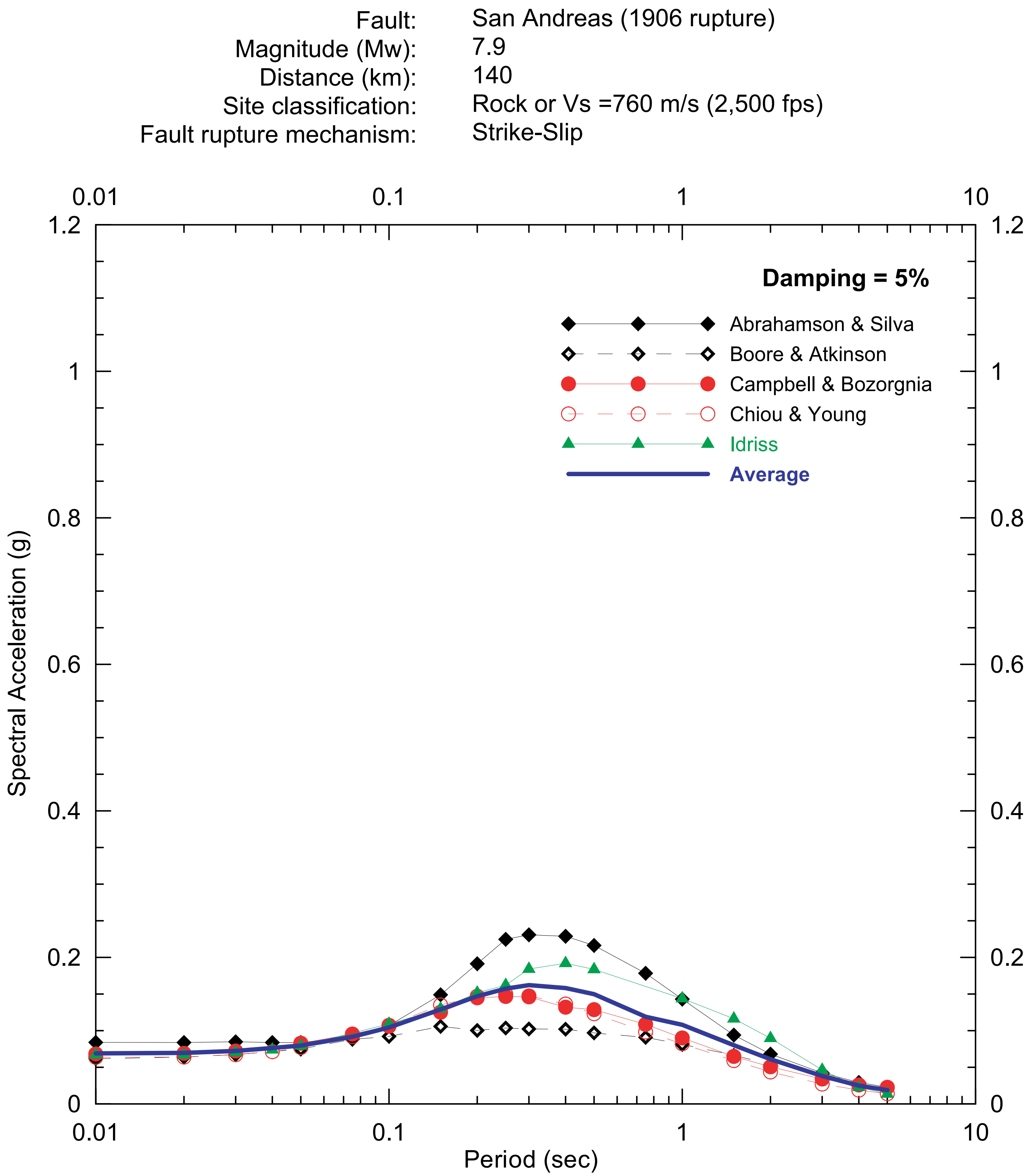

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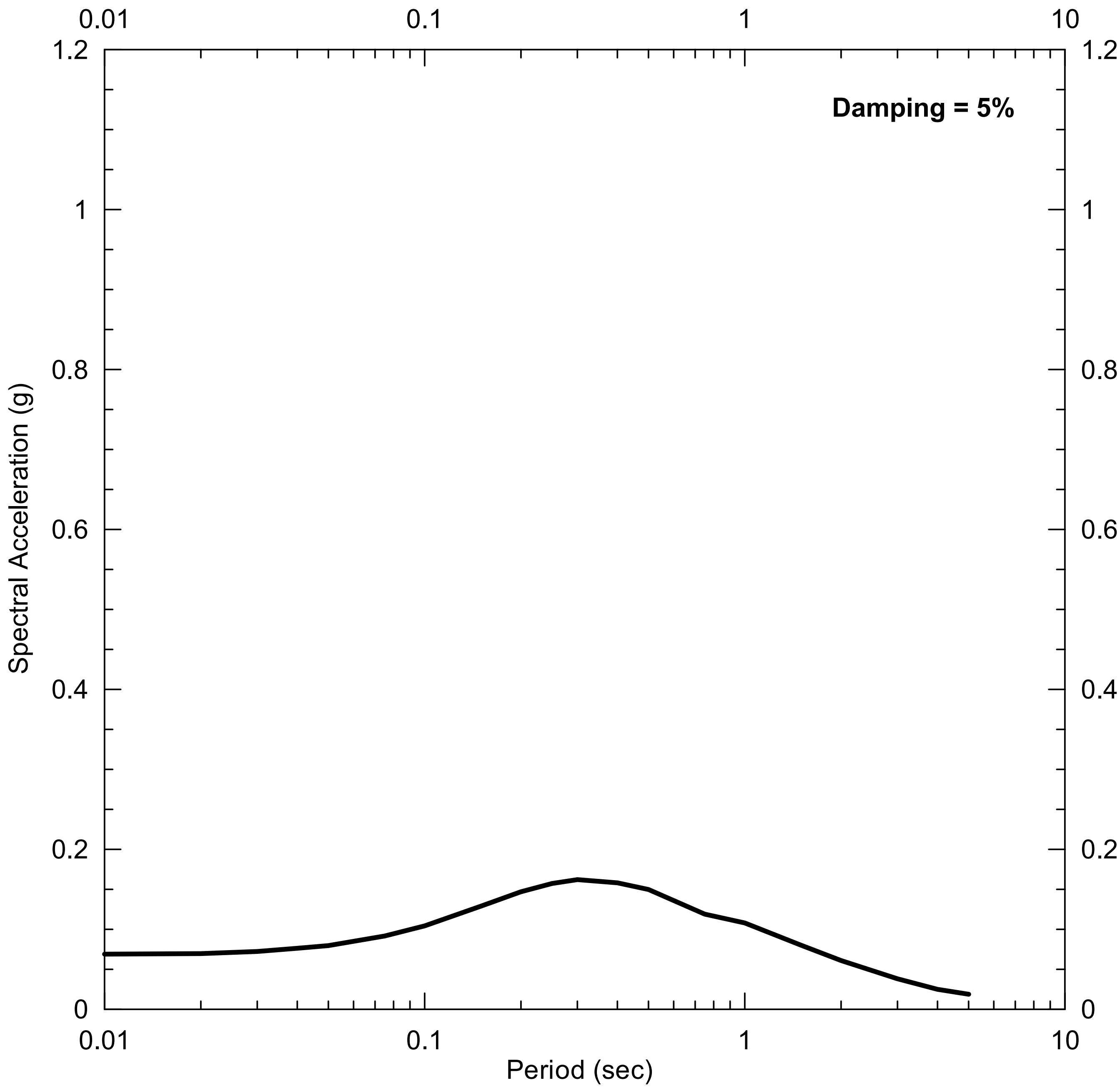
SAN ANDREAS RESPONSE SPECTRA FROM VARIOUS NGA ATTENUATION RELATIONSHIPS

CAMANCHE EMBANKMENTS SAFETY REVIEW

Figure 5-6

Fault: San Andreas (1906 rupture)
Magnitude (Mw): 7.9
Distance (km): 140
Site classification: Rock or Vs =760 m/s (2,500 fps)
Fault rupture mechanism: Strike-Slip



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SAN ANDREAS RESPONSE SPECTRUM

CAMANCHE EMBANKMENTS SAFETY REVIEW

Figure 5-7

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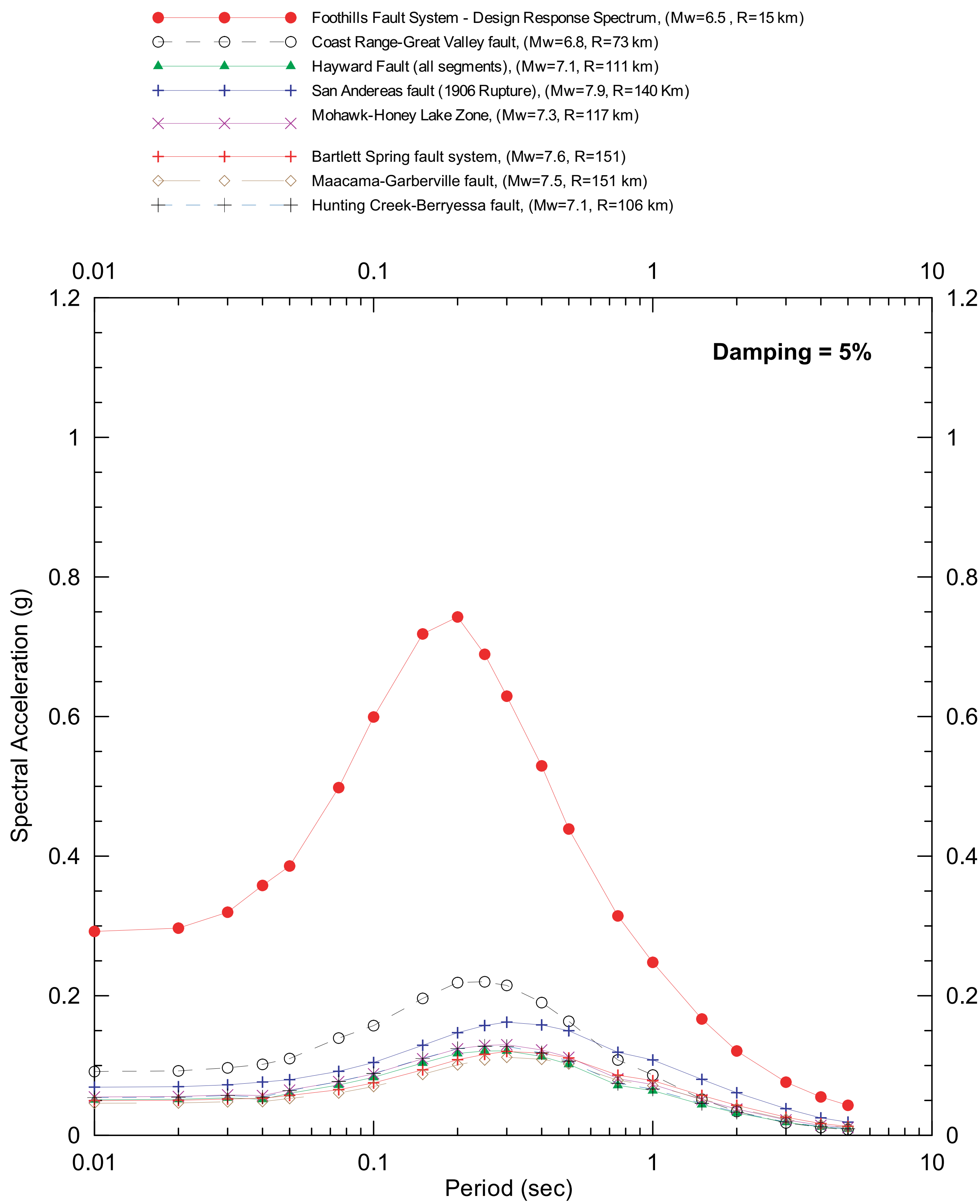

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84^{th} PERCENTILE RESPONSE SPECTRA

CAMANCHE EMBANKMENTS SAFETY REVIEW

Figure 5-8

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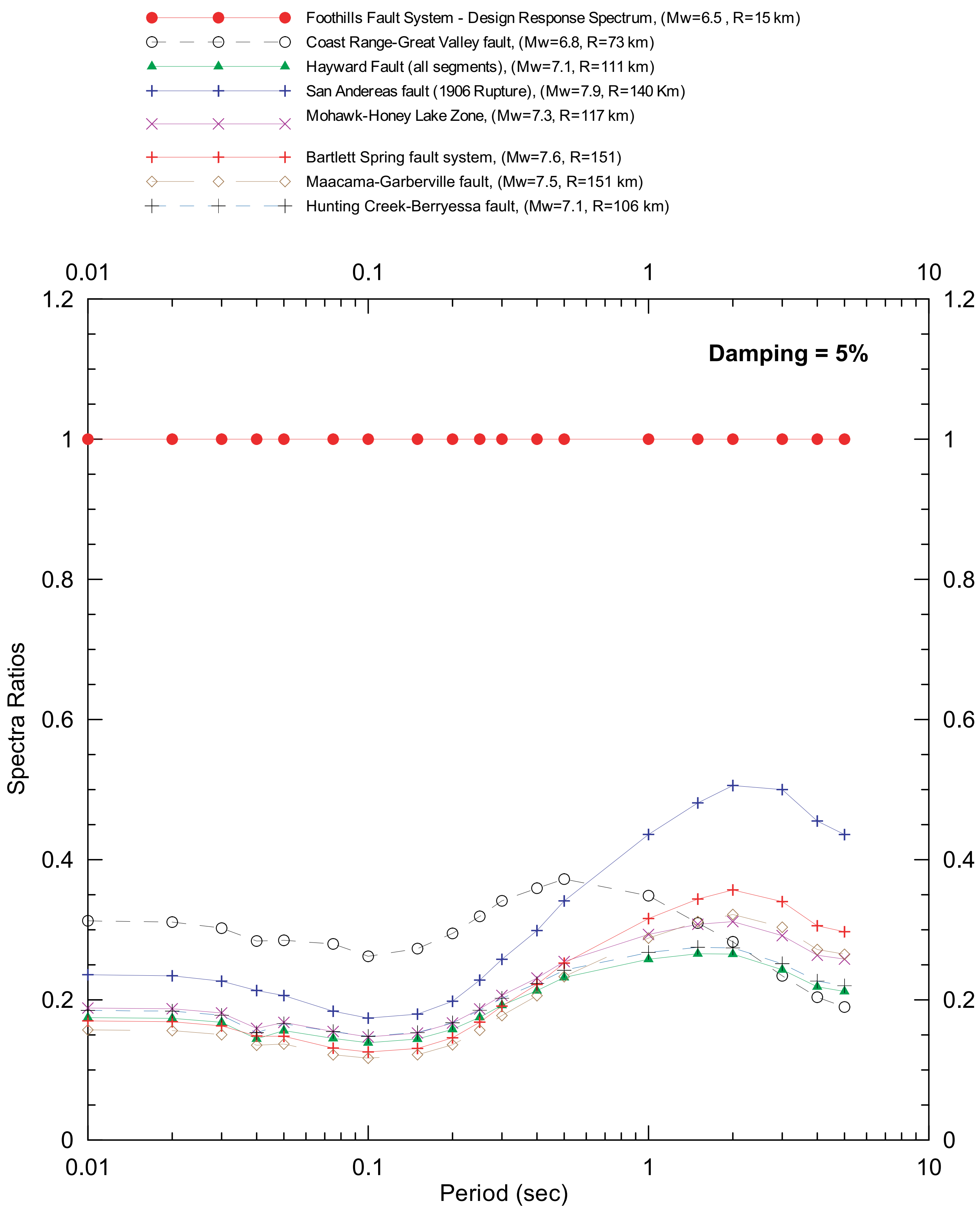

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84th PERCENTILE RESPONSE SPECTRA RATIOS
CAMANCHE EMBANKMENTS SAFETY REVIEW

Figure 5-9

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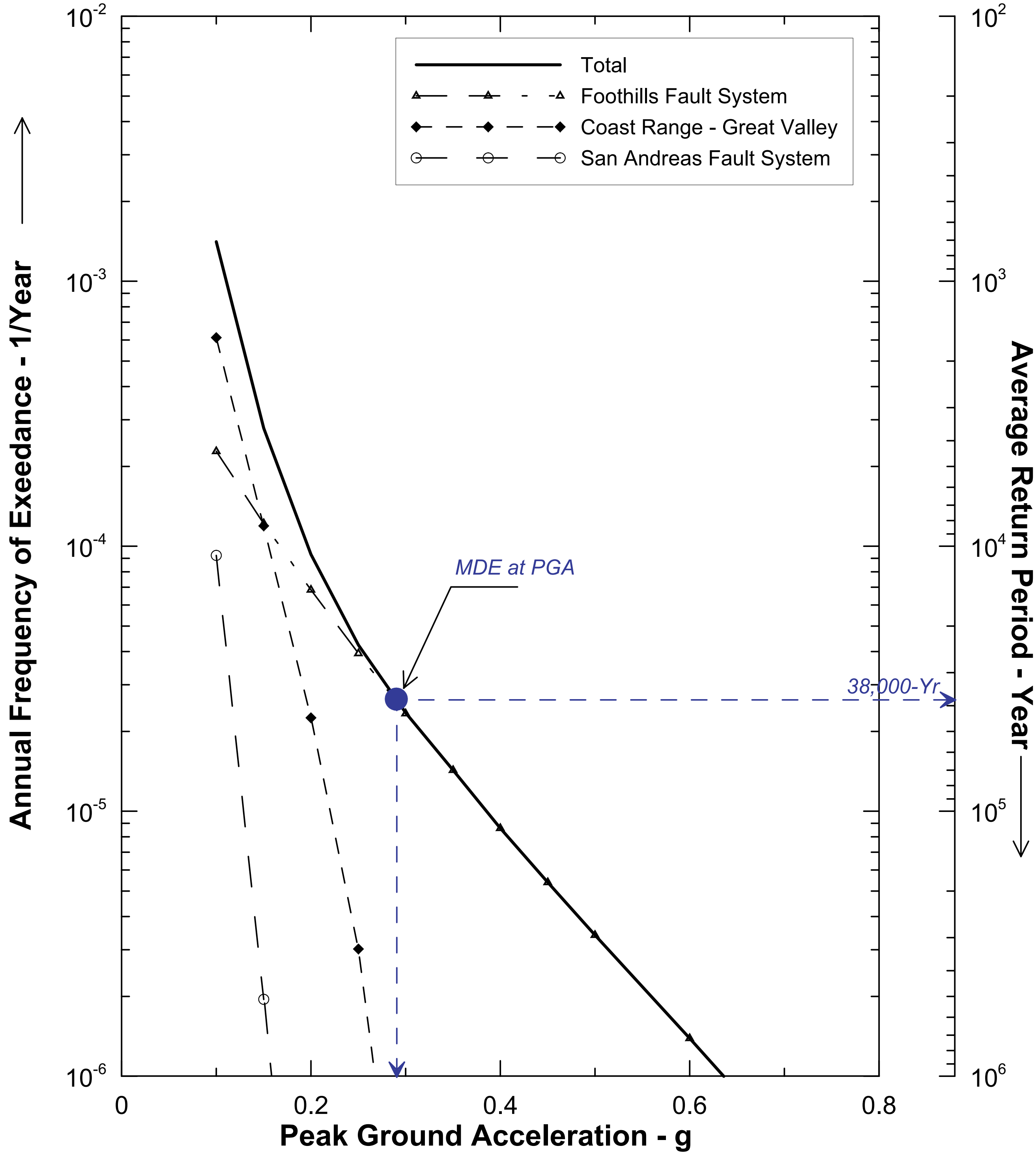

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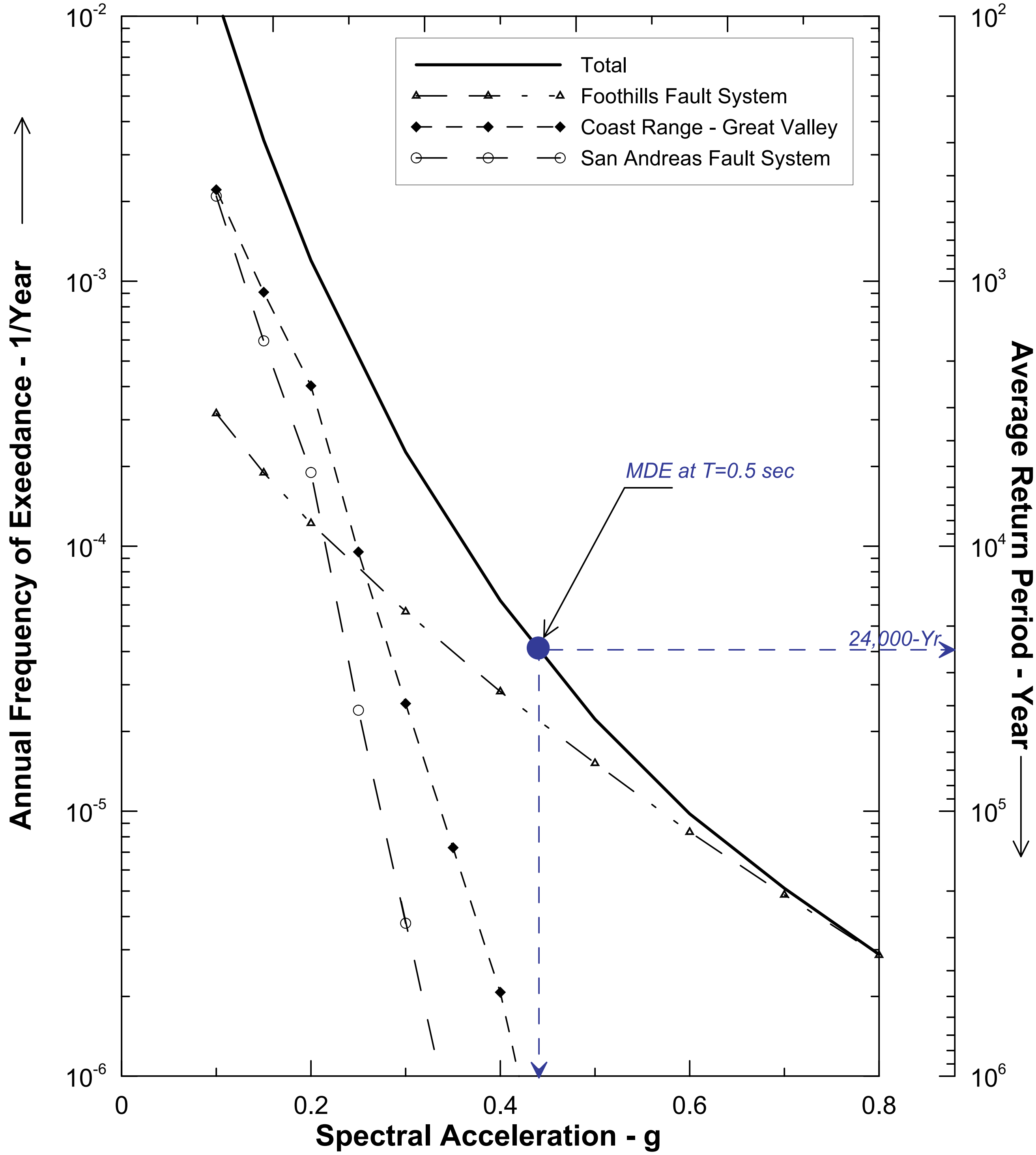
COMPUTED HAZARD CURVES FOR PEAK GROUND ACCELERATION

CAMANCHE EMBANKMENTS SAFETY REVIEW

Figure 5-10



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COMPUTED HAZARD CURVES FOR
SPECTRAL ACCELERATION AT T=0.5 SEC
CAMANCHE EMBANKMENTS SAFETY REVIEW

Figure
5-11

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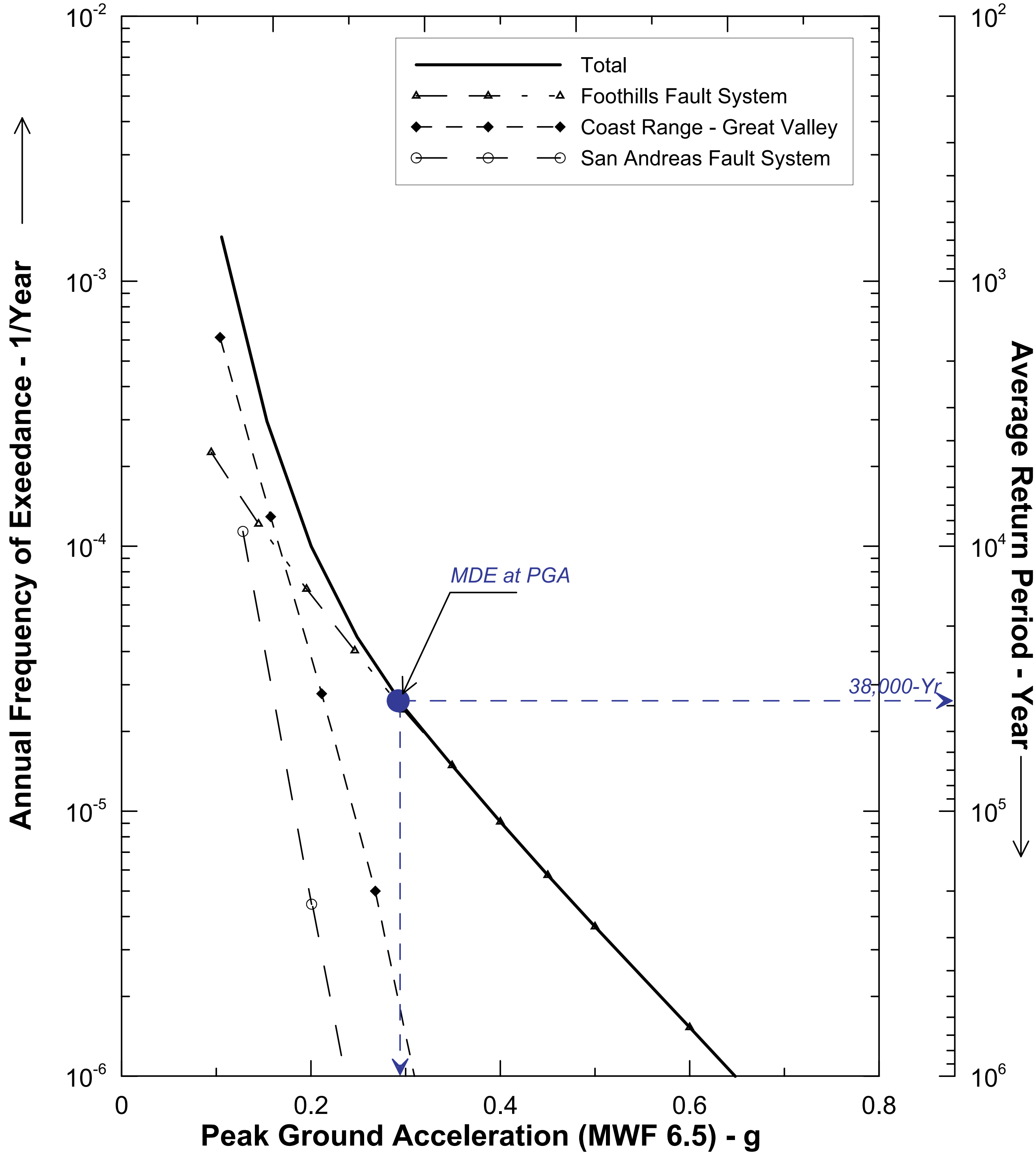

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COMPUTED HAZARD CURVES FOR PEAK GROUND ACCELERATION (MWF 6.5)
CAMANCHE EMBANKMENTS SAFETY REVIEW

Figure 5-12

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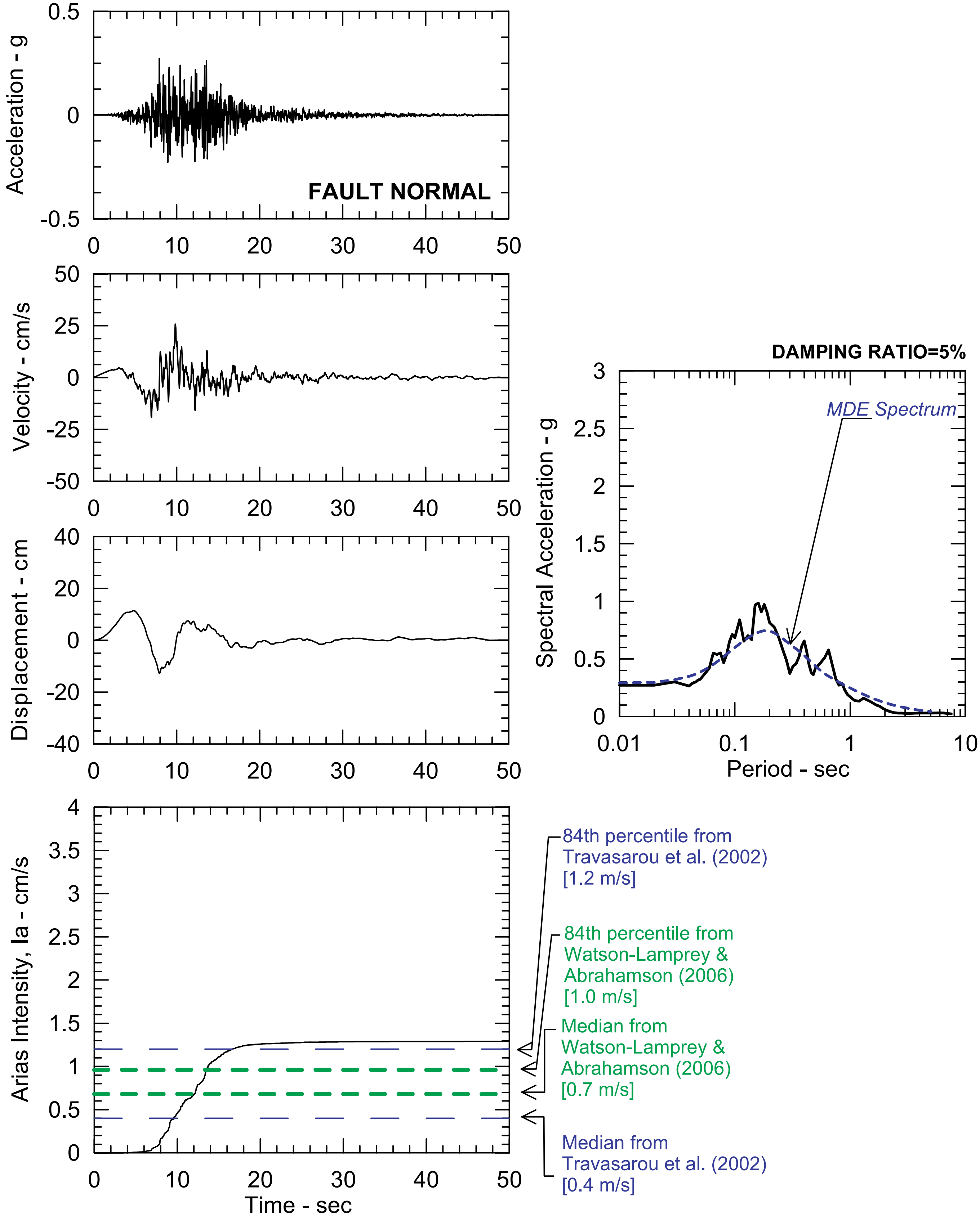

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RECORD TIME HISTORIES, RESPONSE SPECTRUM, AND ARIAS INTENSITY
LOMA PRIETA E/Q, SAN JOSE - SANTA THERESA
CAMANCHE EMBANKMENTS SAFETY REVIEW

Figure 5-13

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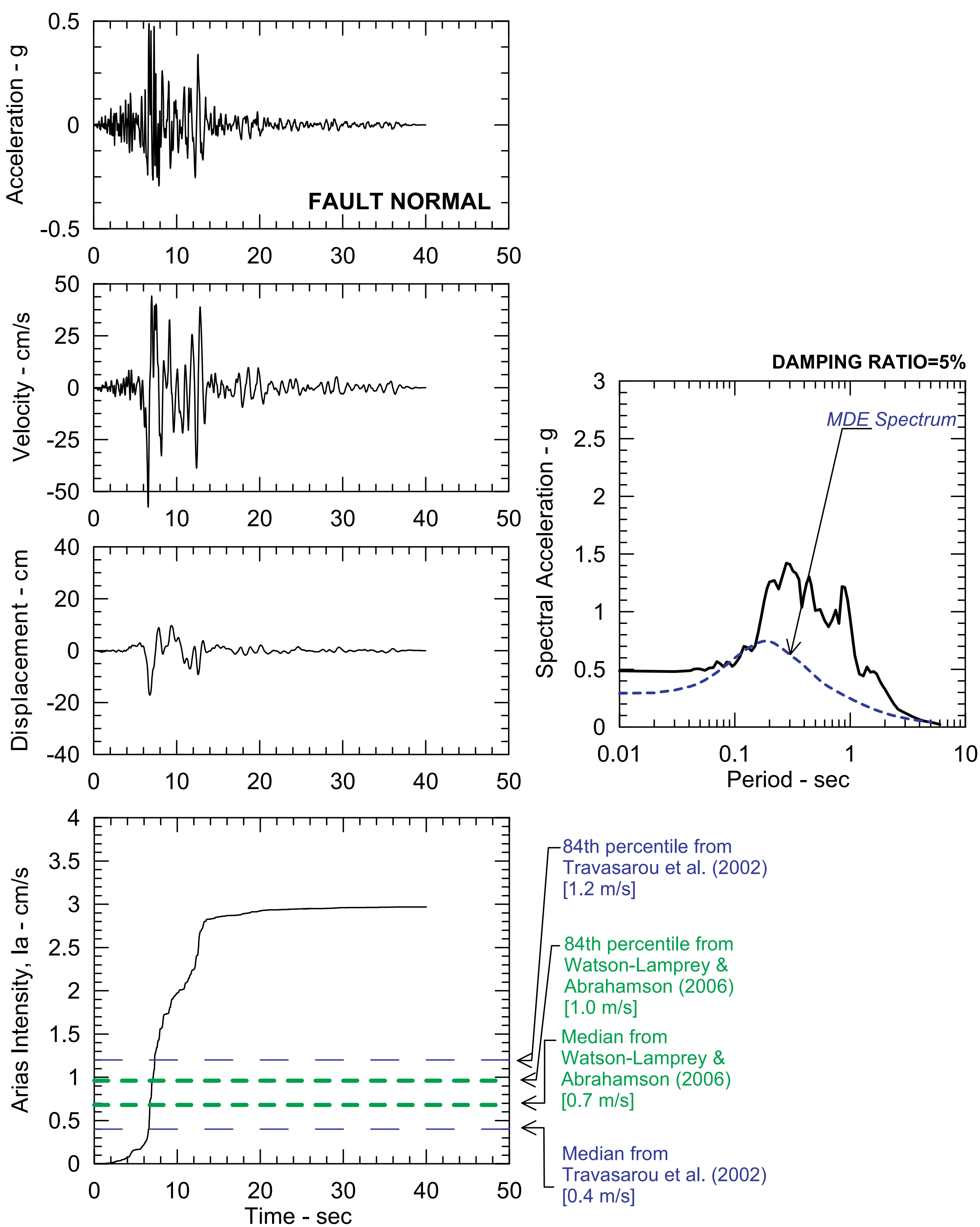

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RECORD TIME HISTORIES, RESPONSE SPECTRUM, AND ARIAS INTENSITY
NORTHRIDGE E/Q, CASTAIC OLD RIDGE ROAD
CAMANCHE EMBANKMENTS SAFETY REVIEW

Figure 5-14

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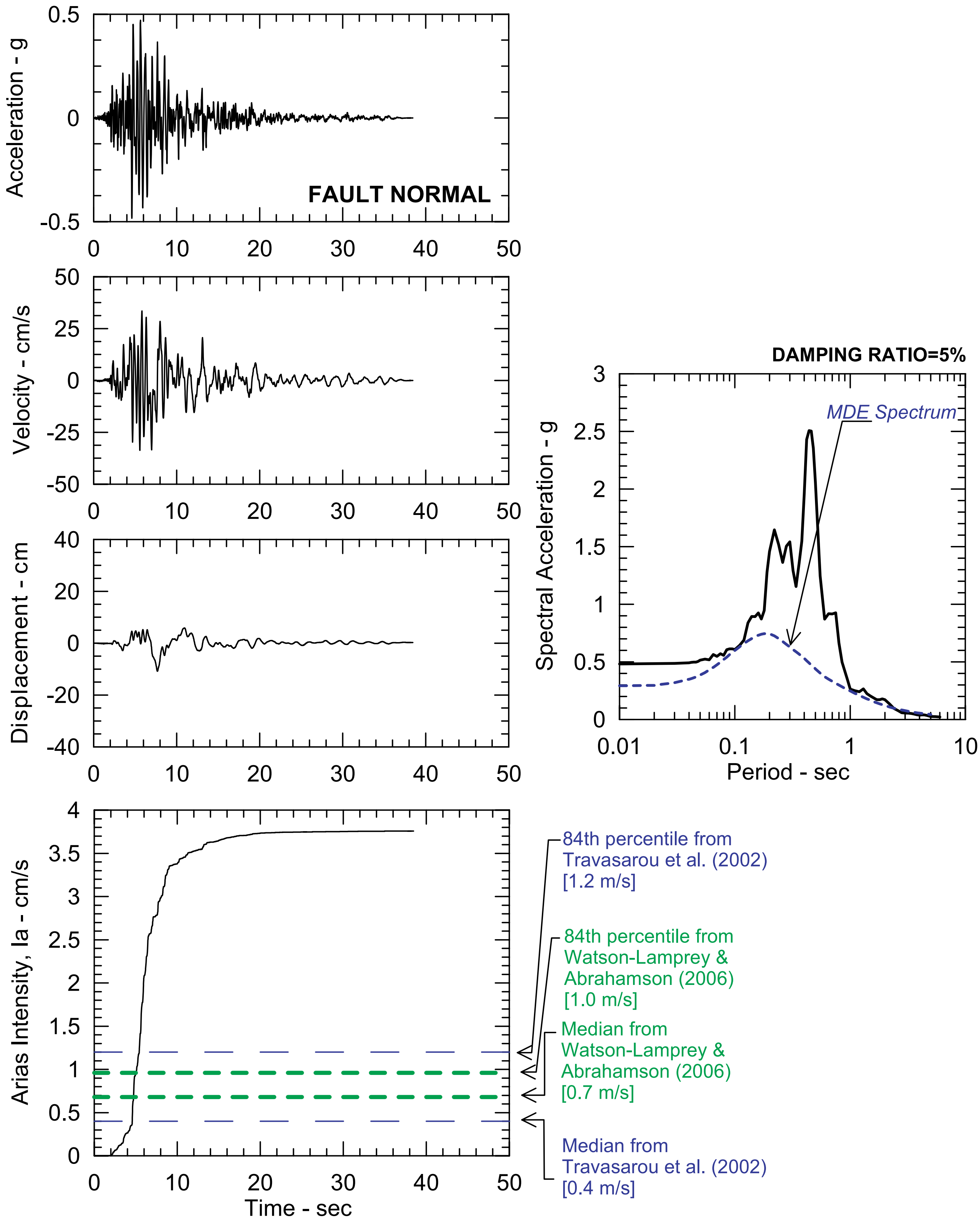

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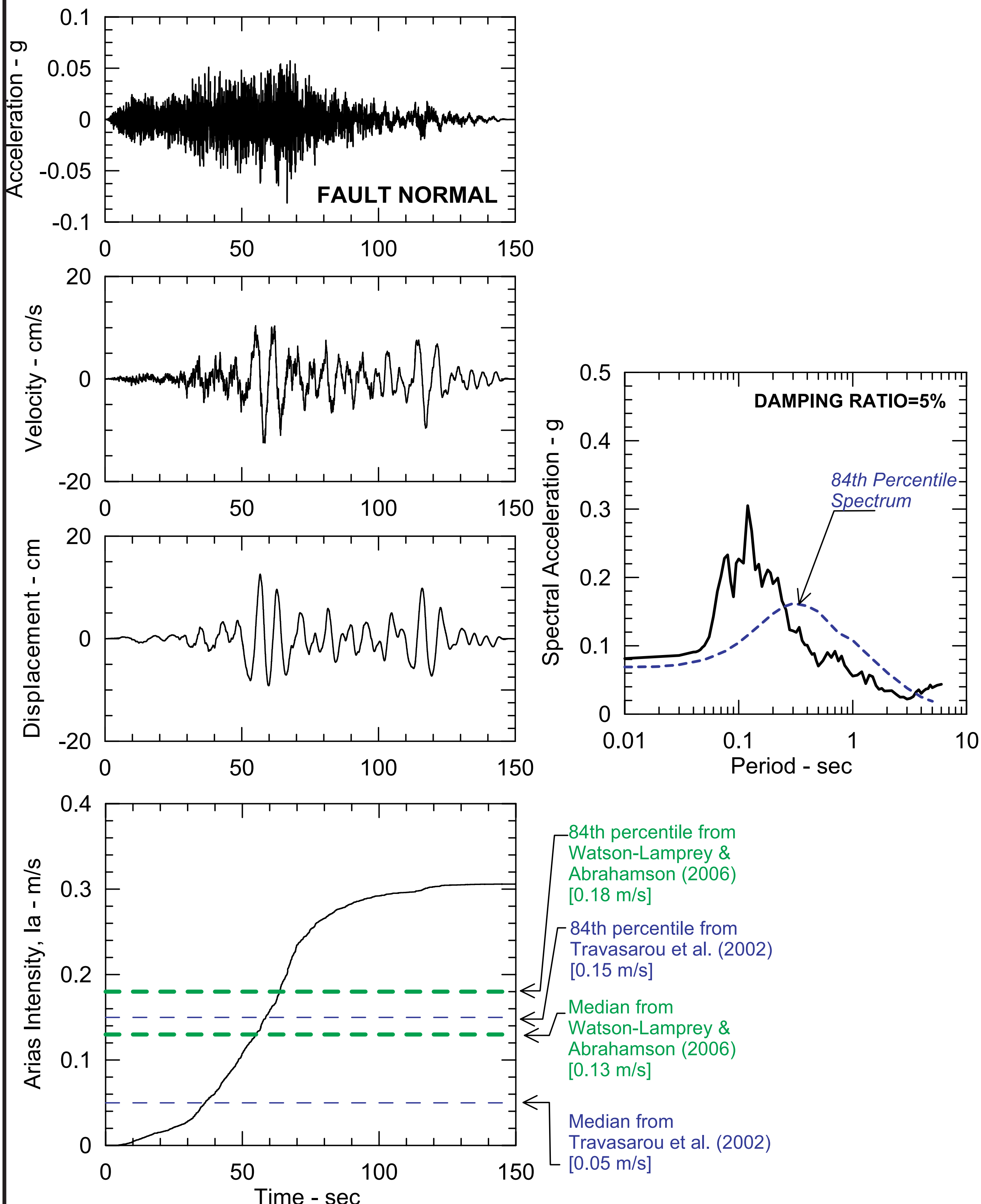
RECORD TIME HISTORIES, RESPONSE SPECTRUM, AND ARIAS INTENSITY
KOBE E/Q, NISHI-AKASHI
CAMANCHE EMBANKMENTS SAFETY REVIEW

Figure
5-15



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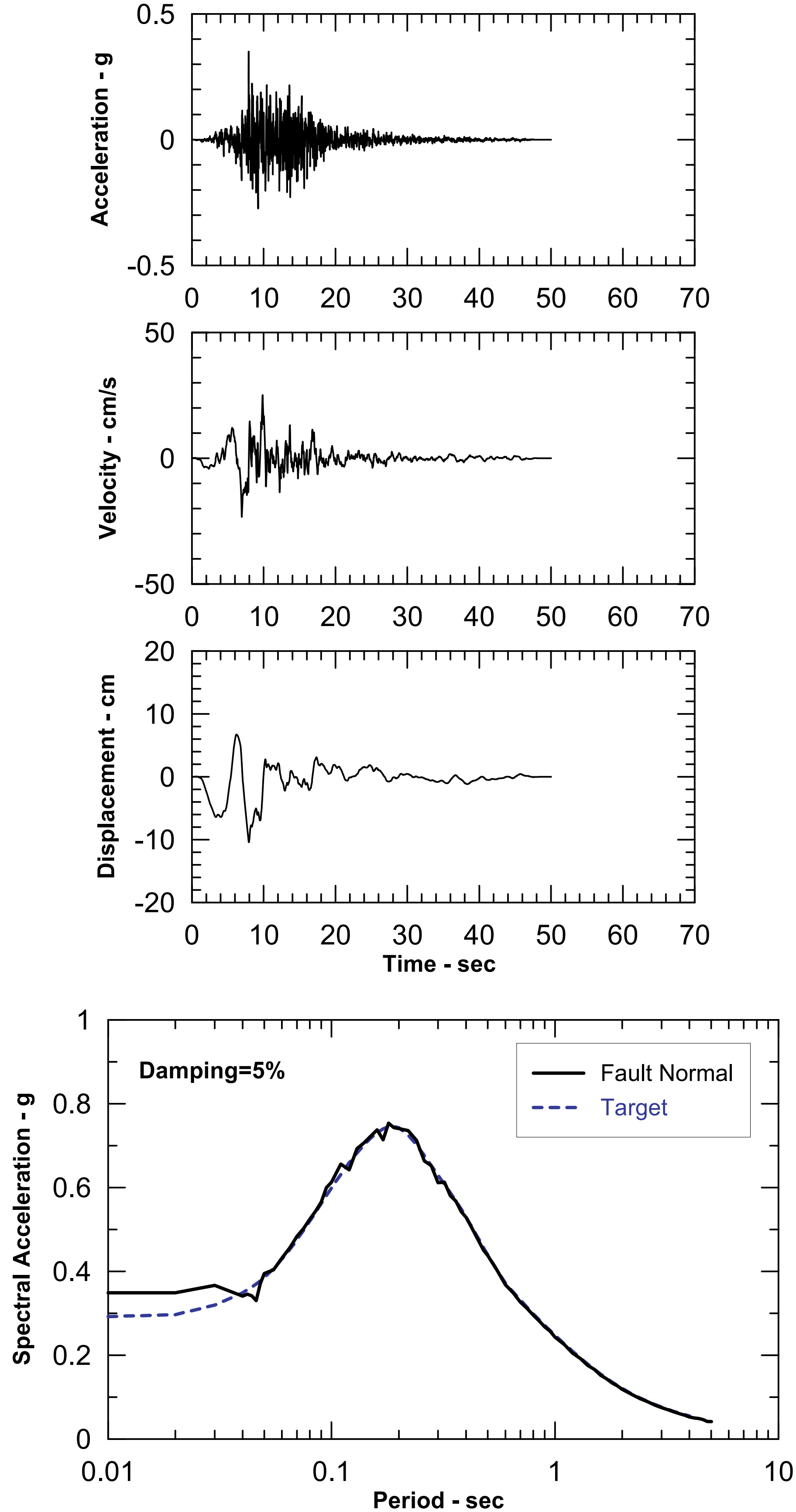
TERRA / GeoPentech a Joint Venture	RECORD TIME HISTORIES, RESPONSE SPECTRUM, AND ARIAS INTENSITY DENALI E/Q, TAPS PUMP STATION 11 CAMANCHE EMBANKMENTS SAFETY REVIEW	Figure 5-16



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ADJUSTED TIME HISTORIES AND RESPONSE SPECTRA
LOMA PRIETA E/Q, SAN JOSE-SANTA THERESA
CAMANCHE EMBANKMENTS SAFETY REVIEW

Figure 5-17

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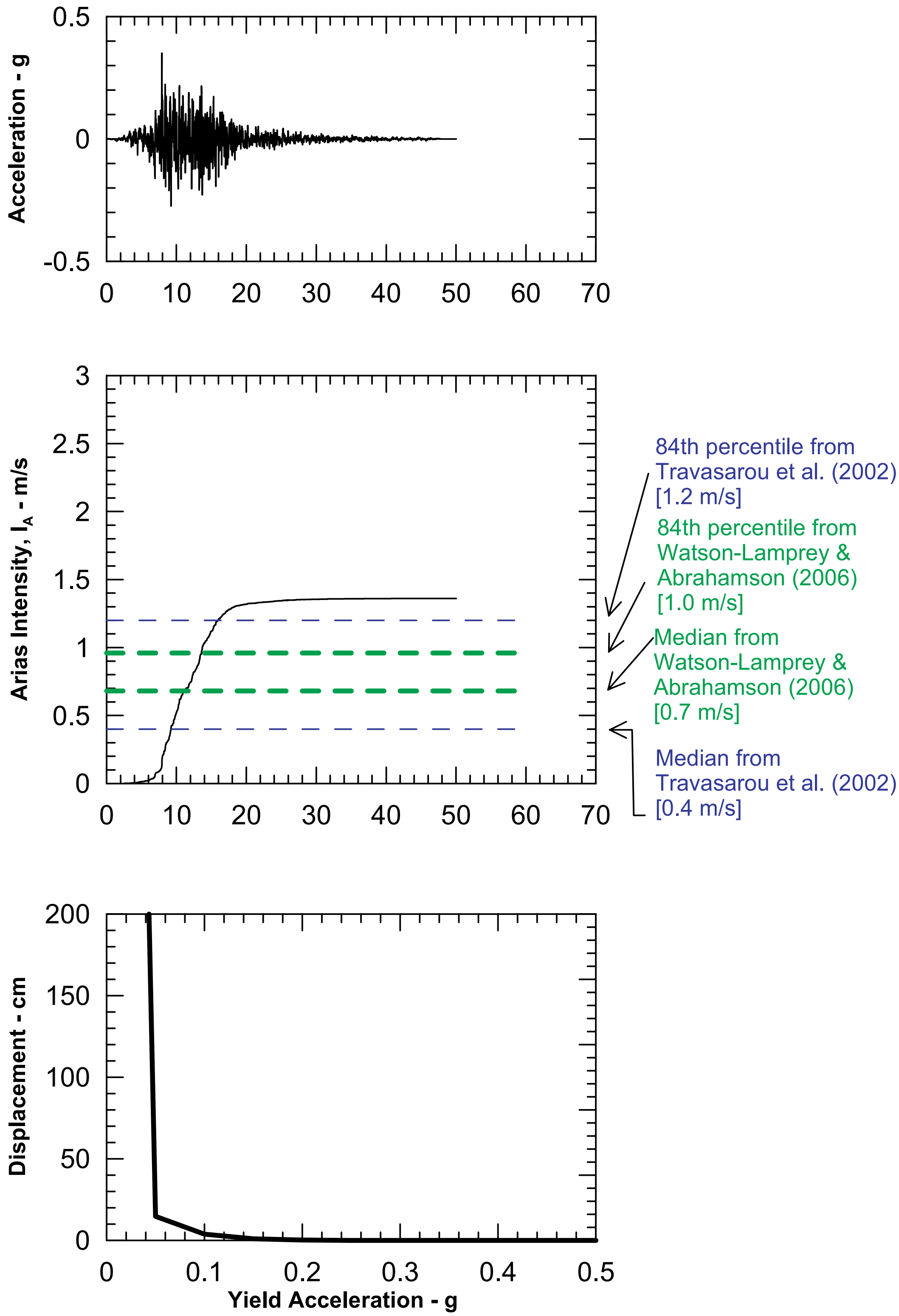

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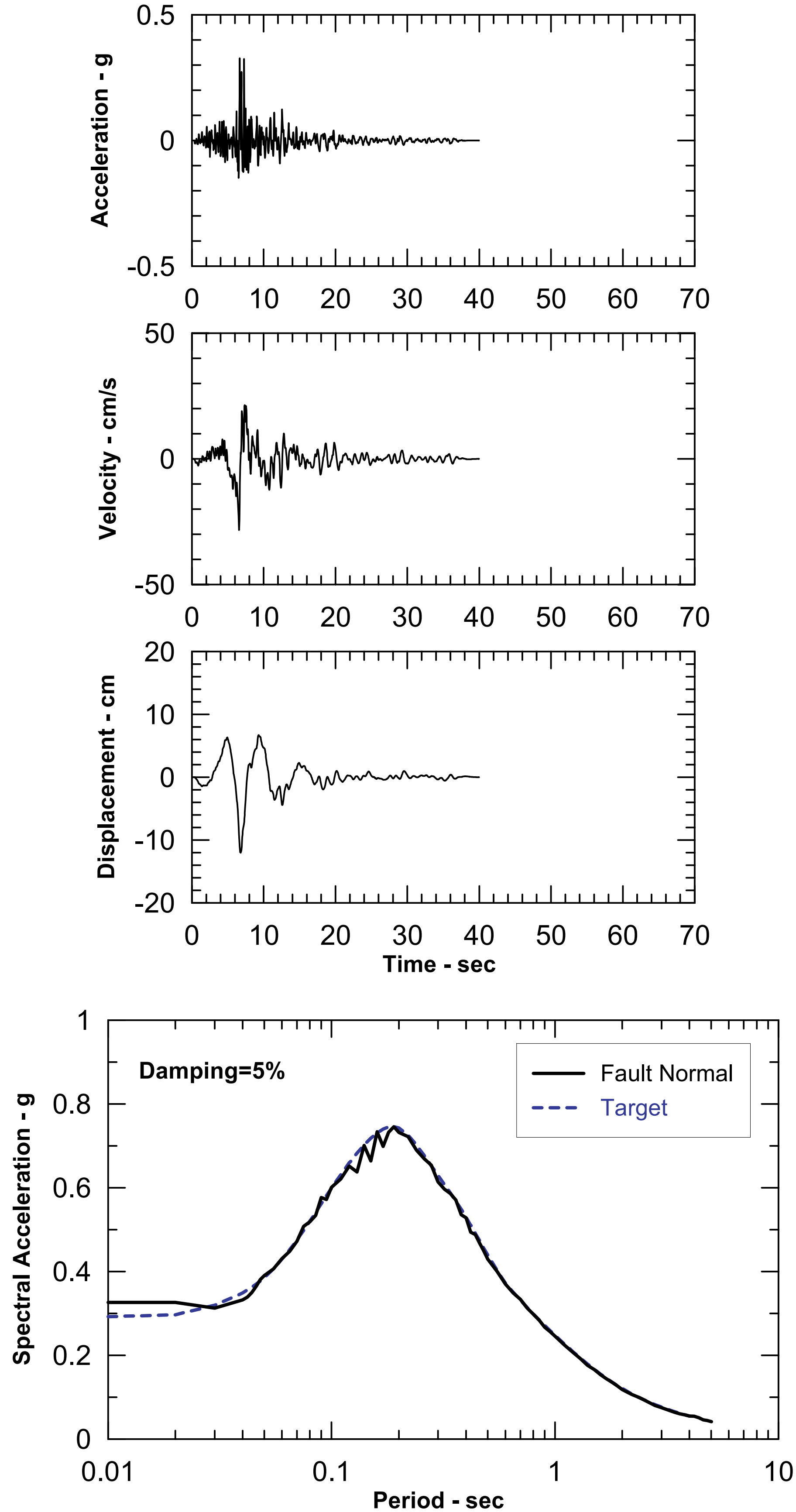
ADJUSTED TIME HISTORIES, ARIAS INTENSITY AND NEWMARK DISPLACEMENT
LOMA PRIETA E/Q, SAN JOSE-SANTA THERESA
CAMANCHE EMBANKMENTS SAFETY REVIEW

Figure 5-18



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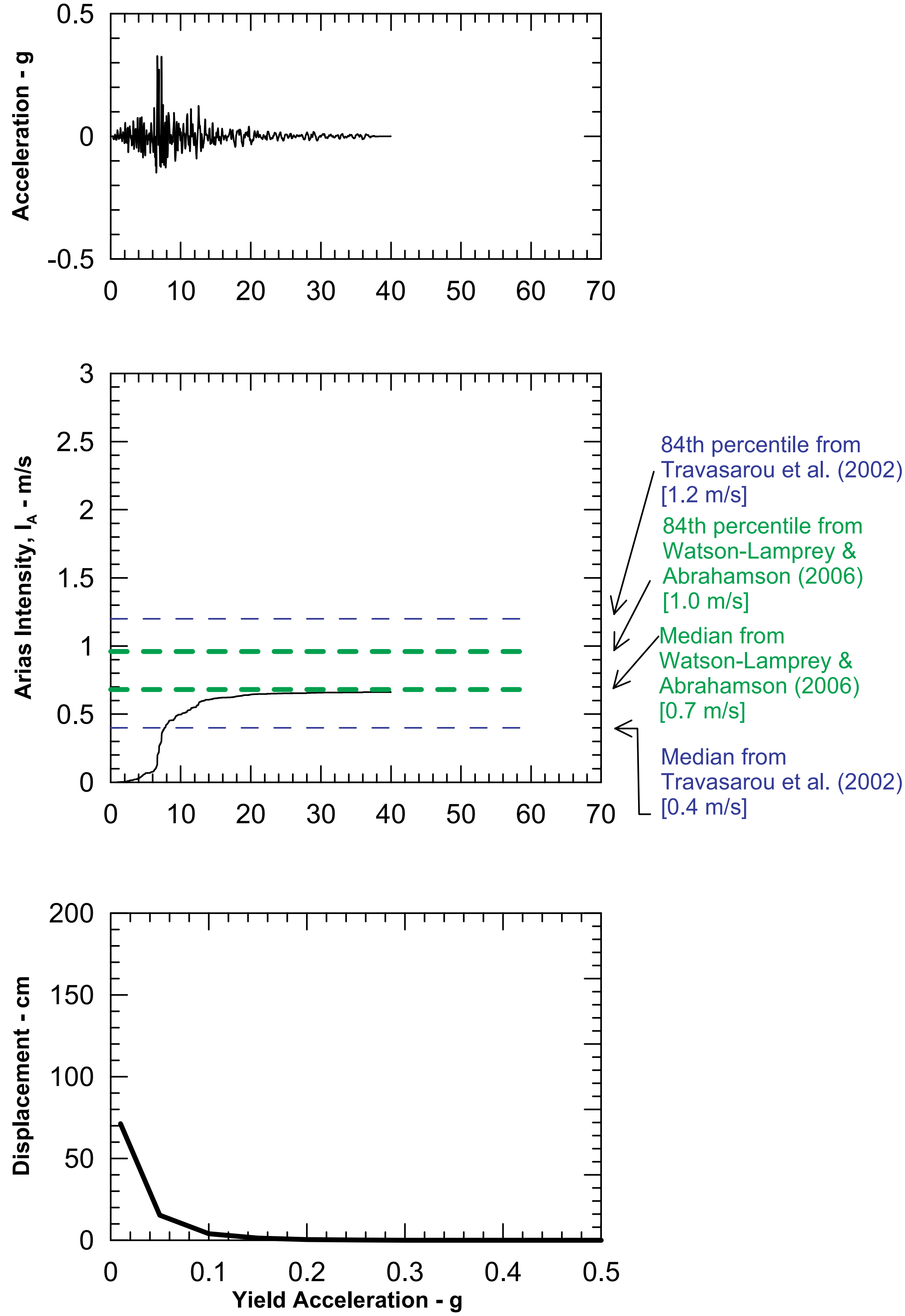
ADJUSTED TIME HISTORIES AND RESPONSE SPECTRA
NORTHRIDGE E/Q, CASTIAC OLD RIDGE ROAD
CAMANCHE EMBANKMENTS SAFETY REVIEW

Figure
5-19



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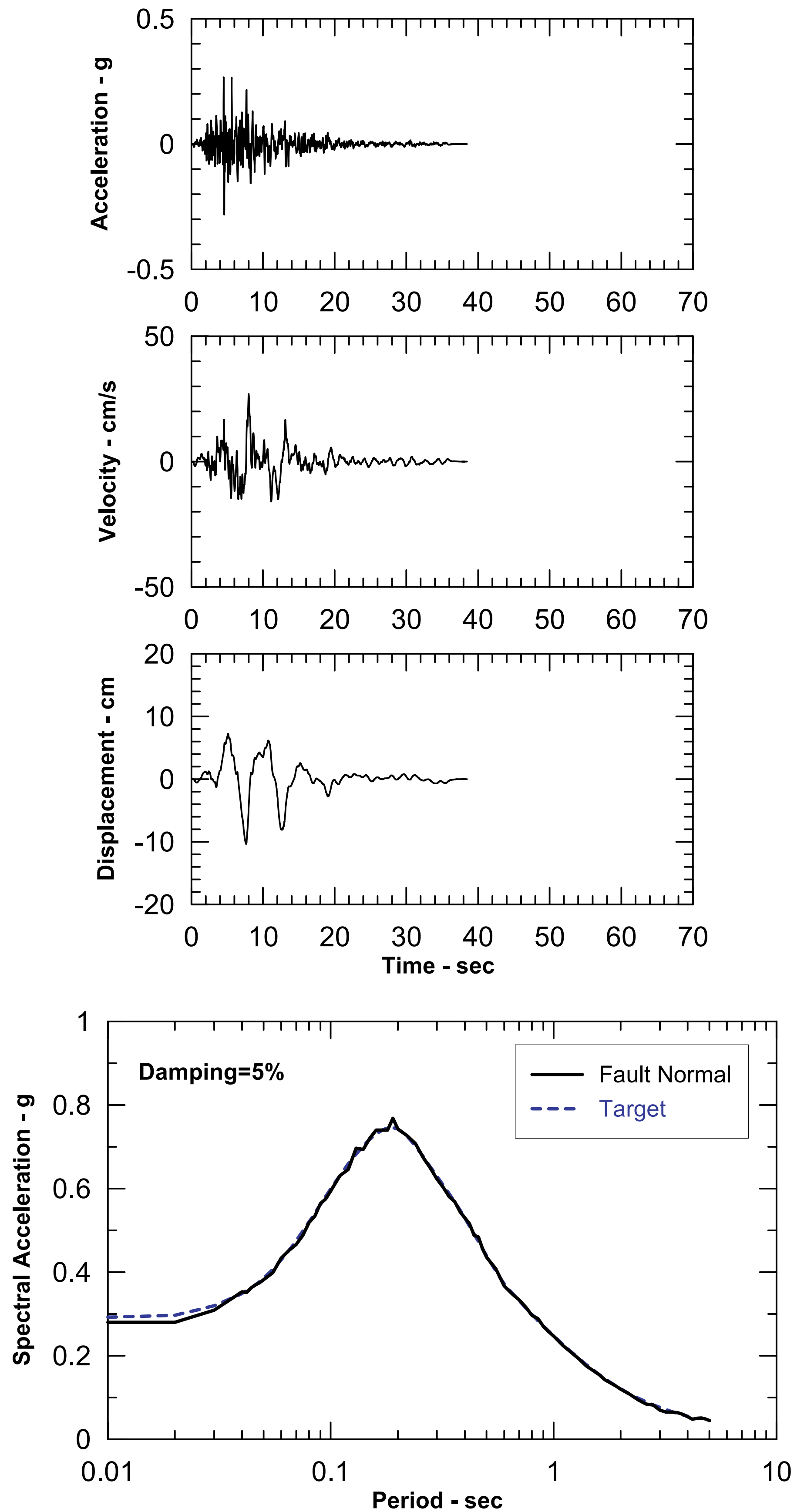
ADJUSTED TIME HISTORIES, ARIAS INTENSITY AND NEWMARK DISPLACEMENT
NORTHRIDGE E/Q, CASTIAC OLD RIDGE ROAD
CAMANCHE EMBANKMENTS SAFETY REVIEW

Figure 5-20



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ADJUSTED TIME HISTORIES AND RESPONSE SPECTRA
KOBE E/Q, NISHI-AKASHI

CAMANCHE EMBANKMENTS SAFETY REVIEW

Figure 5-21

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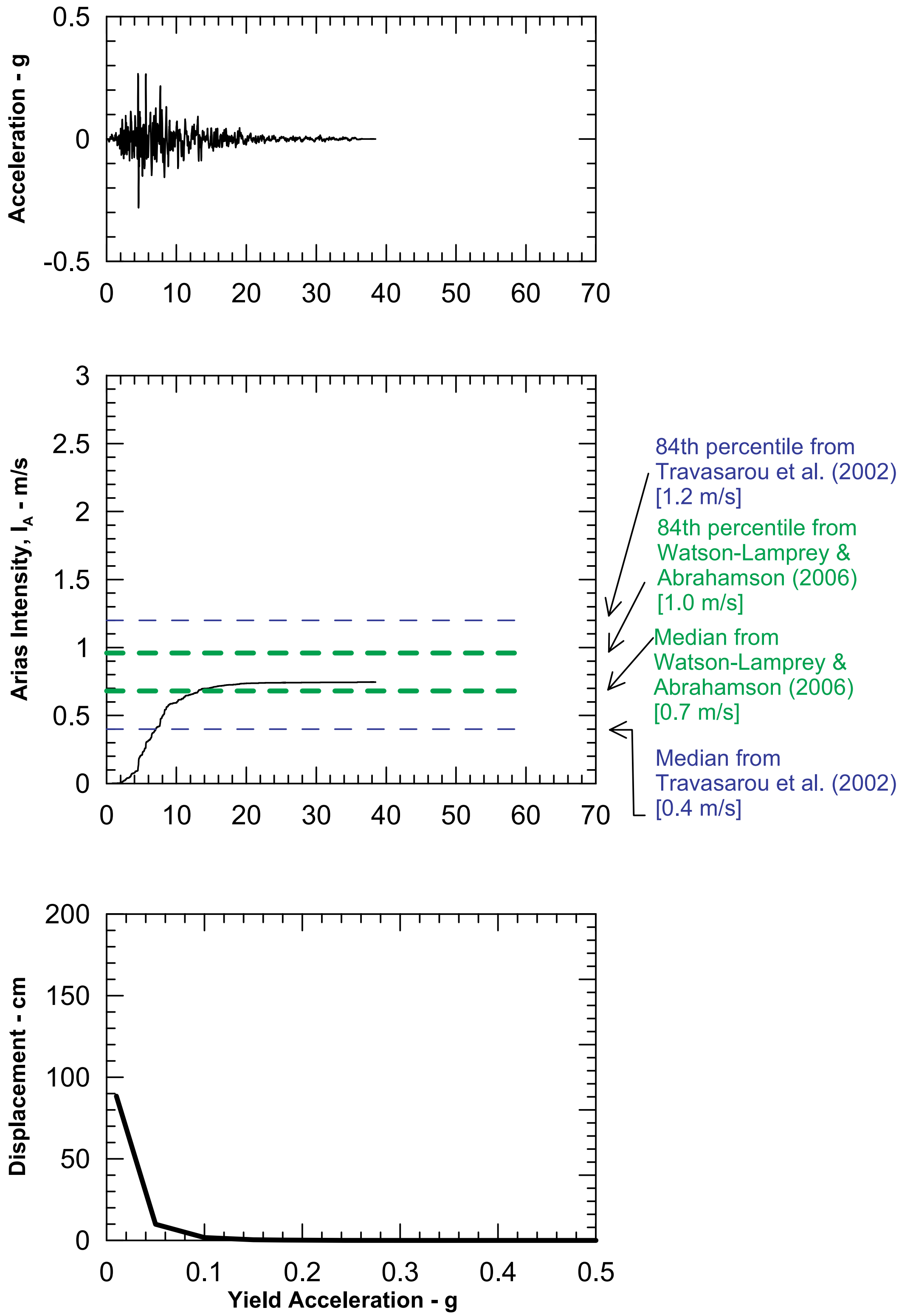
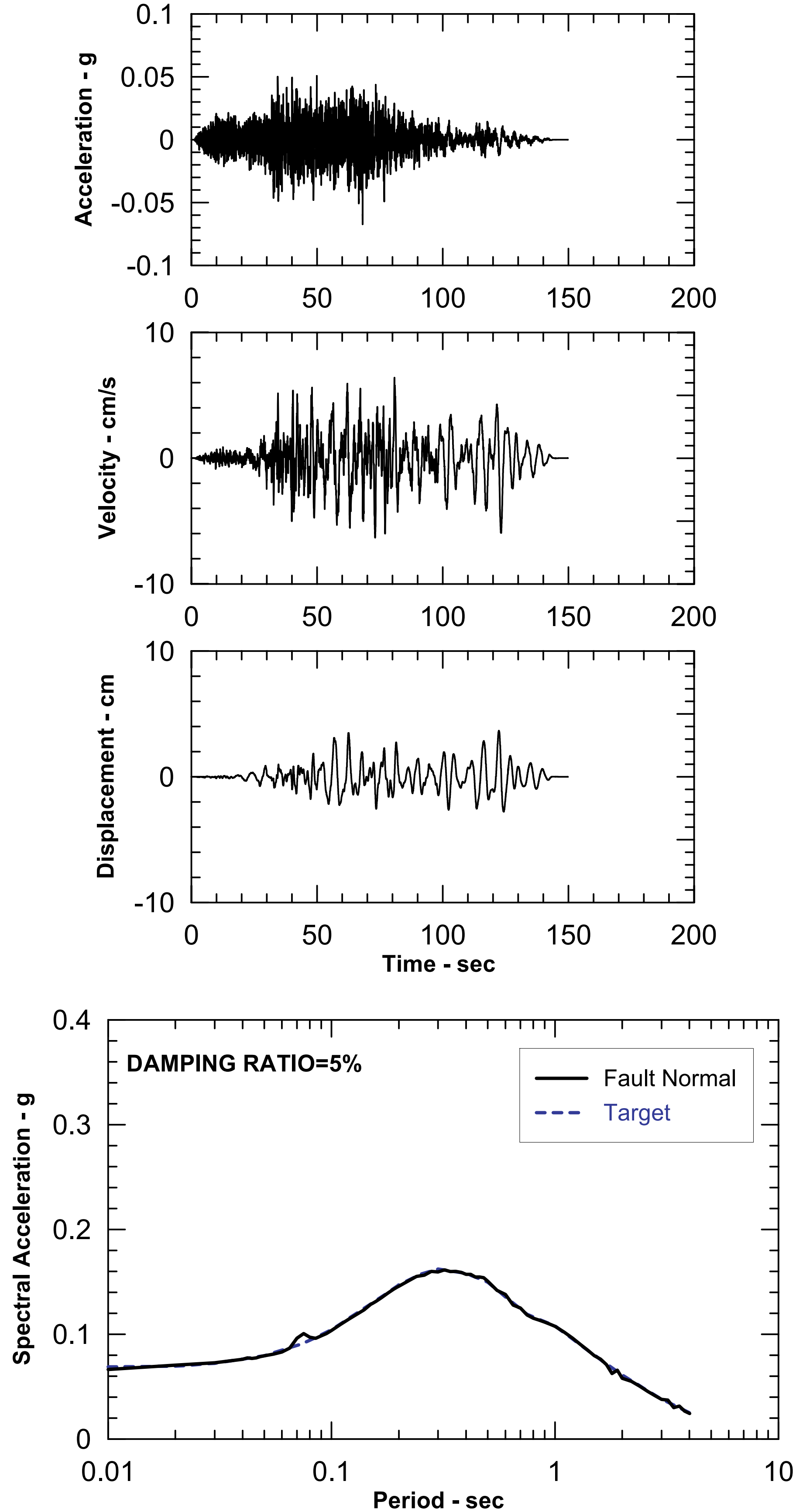


0.5
0
-0.5
Acceleration - g
0
10
20
30
40
50
60
70
3
2.5
2
1.5
1
0.5
0
Arias Intensity, I_A - m/s
84th percentile from Travasarou et al. (2002) [1.2 m/s]
84th percentile from Watson-Lamprey & Abrahamson (2006) [1.0 m/s]
Median from Watson-Lamprey & Abrahamson (2006) [0.7 m/s]
Median from Travasarou et al. (2002) [0.4 m/s]
200
150
100
50
0
Displacement - cm
0
0.1
0.2
0.3
0.4
0.5
Yield Acceleration - g



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ADJUSTED TIME HISTORIES AND RESPONSE SPECTRA
DENALI E/Q, TAPS PUMP STATION 11

CAMANCHE EMBANKMENTS SAFETY REVIEW

Figure 5-23

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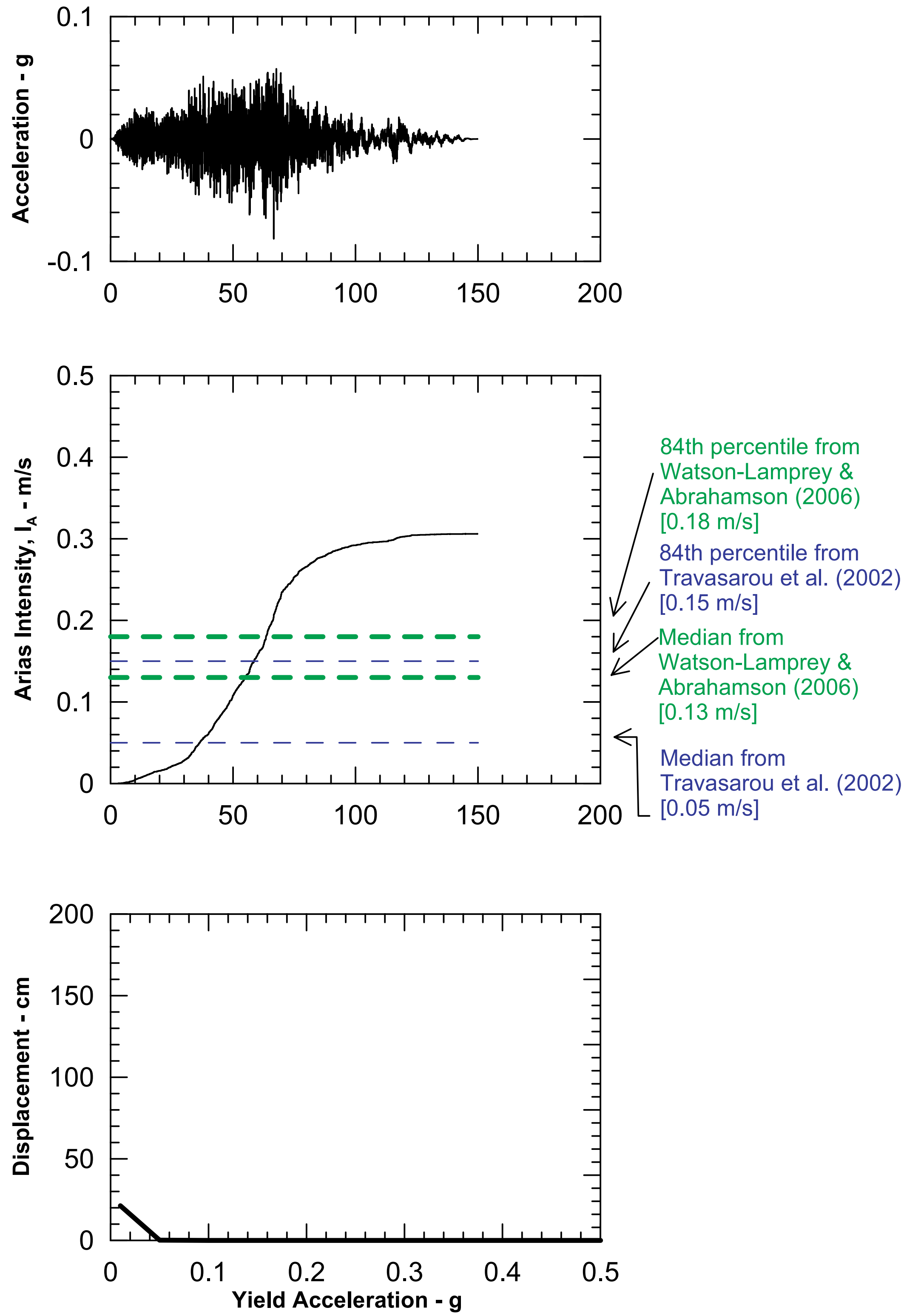

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ADJUSTED TIME HISTORIES, ARIAS INTENSITY AND NEWMARK DISPLACEMENT
DENALI E/Q, TAPS PUMP STATION 11
CAMANCHE EMBANKMENTS SAFETY REVIEW

Figure 5-24