Tennessee Valley Authority Kingston Fossil Plant Harriman, Roane County, Tennessee	**Perimeter Containment** **North Dredge Cell (Dike C) Segment 1** **Sta. A161+50 to A179+50**
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Exhibit 7
Seismic Hazard Analysis

Purpose:

- Define site-specific seismic hazards at Kingston.
- Determine appropriate scenario earthquake parameters.
- Develop appropriate ground motion time histories for input to engineering analyses.

Methods:

- Probabilistic seismic hazard model previously developed (2004) for the TVA service region was used to characterize the hazards at the Kingston site.
- The uniform hazard curves were used to determine peak accelerations having a 2% probability of exceedance in 50 years (2,475-year return period).
- Spectrally matched acceleration time histories were generated.

Results:

- Design earthquake events with 2,475-year return period:
  Local event, **M** = 6.0, distance = 36 km
  New Madrid event, **M** = 7.6, distance = 435 km
- For each scenario earthquake, produced 3 sets of orthogonal acceleration time histories.

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FINAL REPORT
DEVELOPMENT OF EARTHQUAKE GROUND MOTIONS FOR THE KINGSTON FOSSIL PLANT SITE

Submitted to:
Tennessee Valley Authority, Chattanooga, TN

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AMEC Geomatrix

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EXECUTIVE SUMMARY

This report documents the development of earthquake ground motions for use in the seismic analysis of the Kingston Fossil Plant facilities. The work was conducted in two steps. The first step involved assessment of the seismic hazard at the Kingston site. This assessment was conducted using the seismic hazard model of the TVA service area developed for the TVA Dam Safety Program. The product of this analysis is a uniform hazard response spectrum (UHRS) representing ground motions at the site with a return period of 2,475 years (or equivalently, a 2 percent probability of being exceeded in a 50-year time period).

The second step involves development of acceleration time histories for use in dynamic analyses of plant facilities. These time histories are developed for two scenario earthquakes that represent the primary contributors to the ground shaking hazard at the site. The first primary source is the occurrence of earthquakes randomly in the site region. These earthquakes are represented by the scenario of a magnitude **M** 6 earthquake occurring at a distance of 36 km. The second primary source is the occurrence of a large-magnitude earthquake occurring in the New Madrid seismic zone. This is represented by the scenario of a magnitude **M** 7.6 earthquake occurring at a distance of 435 km from the site.

Three sets of acceleration time histories were developed for each scenario earthquake. Each set consists of three orthogonal components of motions. The time histories were selected from a database of strong ground-motion recordings developed to represent central and eastern United States earthquake motions. The time histories were adjusted so that their response spectra match the target response spectra for the scenario earthquakes at 5 and 7 percent damping. The scenario earthquake response spectra and the resulting ground-motion time histories represent surface motions on a site composed of hard rock (shear-wave velocity in excess of 9,000 fps).

DEVELOPMENT OF EARTHQUAKE GROUND MOTIONS FOR THE KINGSTON FOSSIL PLANT SITE
Roane County
Tennessee

1.0 INTRODUCTION

This report documents the development of earthquake ground motions for use in the seismic analysis of the Kingston Fossil Plant facilities. The work was conducted in two steps. The first step involved assessment of the seismic hazard at the Kingston site. This assessment was conducted using the seismic hazard model for the TVA service region developed by Geomatrix (2004). The product of this analysis is a uniform hazard response spectrum (UHRS) representing ground motions at the site with a return period of 2,475 years (or equivalently, a 2 percent probability of being exceeded in a 50-year time period). The second step involves development of acceleration time histories for use in dynamic analyses of plant facilities. These time histories are developed to represent scenario earthquakes that are the primary contributors to the ground shaking hazard at the site. The results of these two analysis steps are described below.

2.0 SEISMIC HAZARD ASSESSMENT

A comprehensive seismic hazard model of the TVA service region was developed by Geomatrix (2004) for the TVA Dam Safety Program. The seismic hazard model included potential sources of future earthquakes that might affect the region extending from western North Carolina to the Mississippi River and from southern Kentucky to northern Mississippi, Alabama, and Georgia. Figure 1 shows the seismic sources. The seismic hazard model was probabilistic in that it defined not only the potential locations for future earthquakes but also the frequency at which these earthquakes are expected to occur. The seismic hazard model also addressed the uncertainties in characterizing the seismic hazard in the region through a formal process of incorporating alternative interpretations of earthquake sources and earthquake ground motions to capture the range in current scientific knowledge. The seismic hazard model went through a formal review process by an independent expert panel. Details of the seismic hazard model are provided in Geomatrix (2004).

The TVA Dam Safety seismic hazard model was used to compute the seismic hazard for the Kingston site (latitude 35.91 deg N, longitude 84.51 deg W). Probabilistic seismic hazard calculations were performed for 10 ground motion measures, peak ground acceleration (PGA), and response spectral acceleration (PSA) at spectral periods of 0.02, 0.03, 0.04, 0.1, 0.2, 0.4, 1.0, 2.0, and 4.0 seconds (spectral frequencies of 50, 33,

25, 10, 5, 2.5, 1, 0.5, and 0.25 Hz, respectively). The ground motion models used in the calculations were those developed by EPRI (2004) for the assessment of earthquake hazards at nuclear power plants in the central and eastern United States (CEUS). The ground motion models represent surface motions on hard rock (shear wave velocities in excess of approximately 9,000 fps. These ground motion models were extended to cover additional spectral periods for TVA by Geomatrix (2004). The hazard calculations were conducted considering all potential earthquakes that may affect the site that have moment magnitudes of **M** 5 and larger.

The results of these calculations are a series of seismic hazard curves that define the relationship between ground motion amplitude and return period. These hazard curves were then interpolated to obtain the ground motion amplitudes for each ground motion measure that have a return period of 2,475 years (a 2 percent probability of being exceeded in a 50-year period). These values define the UHRS for the site listed in Table 1. The selected hazard level, a return period of 2,475 years, is the same as the most conservative hazard values published in the U.S. Geological Survey's most recent (2008) national seismic hazard maps (Petersen et al., 2008). The use of 2 percent probability of exceedance in 50 years (2,475-year return period) is slightly more conservative than the 10 percent probability of exceedance in 250 years (2,373-year return period) defined for the maximum horizontal ground motion in the Tennessee Department of Environment and Conservation regulation on solid waste processing and disposal (Chapter 1200-1-7).

3.0 TIME HISTORY DEVELOPMENT

3.1 SCENARIO EARTHQUAKE SPECTRA

Sets of acceleration time histories were developed to represent earthquake ground motions that may be generated at the Kingston site. These time histories were developed for two scenario earthquakes. The scenario earthquakes are defined to be representative of earthquake motions that produce the UHRS given in Table 1. The scenarios are selected by examining the deaggregation of the seismic hazard results in terms of earthquake magnitude and source-to-site distance. Figure 2 shows the deaggregation of the 10 Hz and 1 Hz hazard results for the Kingston site. The spectral frequency of 10 Hz is selected to represent a typical structural frequency of stiff industrial structures, and 1 Hz is selected to represent structures that respond more strongly to low frequency motions, such as embankment dams. Each plot shows the percent contribution from earthquakes in various magnitude and distance intervals.

The results for 10 Hz motions indicate that there are two primary sources of hazard. The majority of the hazard is due to moderate magnitude earthquakes (**M** 5 to about 6.5)

occurring in the general vicinity of the site (within about 100 km). The second source of hazard is large-magnitude earthquakes occurring at distances of over 400 km. The source of large, distant earthquakes is the New Madrid seismic zone, located approximately 435 km from the site. The distant New Madrid source becomes the primary hazard contributor for 1 Hz spectral accelerations, as indicated in the lower plot of Figure 2.

Based on the results shown on Figure 2, two scenario earthquakes were defined. The first represents the mode of the hazard deaggregation for 1 Hz. This event has a magnitude of 7.6 and falls in the distance range of 400 to 500 km. The distance used is 435 km, the average minimum distance to the New Madrid source. An 84th percentile deterministic response spectrum was computed for this earthquake to use as the horizontal 1 Hz scenario target ground-motion spectrum. The spectrum was computed using the EPRI (2004) models for median ground motions along with the updated EPRI (2006) models for aleatory variability. The resulting spectral accelerations are listed in Table 2. The vertical spectrum was taken to be 0.8 times the horizontal spectrum based on recorded ground-motion data obtained by TVA at similar types of sites.

The second scenario earthquake was defined by computing the average magnitude and distance for earthquakes contributing to the 10 Hz hazard at distances of 100 km or less. This scenario represents an earthquake occurring randomly within the site region. The average magnitude was **M** 5.7 and the average distance was 36 km. The scenario magnitude was increased to **M** 6 in order to provide a somewhat broader spectral shape for analysis of the facility. An 84th percentile spectral shape was computed for this event, and the result was scaled to match the UHRS at a frequency of 10 Hz to produce the 10 Hz scenario horizontal target spectrum. The vertical target spectrum was again taken to be 0.8 times the horizontal target spectrum. The 10 Hz scenario spectra are listed in Table 3. The 10 Hz scenario horizontal spectrum was scaled to match the UHRS because it represents multiple possible earthquakes that may affect the site.

Figure 3 compares the 5 percent damped horizontal spectra for the scenario earthquakes with the 2,475-year UHRS. The 5 and 7 percent damped horizontal and vertical acceleration response spectra for the scenario earthquakes are shown on Figures 4 and 5 and are listed in Tables 3 and 4. The response spectra for vertical motions were obtained by multiplying the horizontal response spectra by a factor of 0.8 at all frequencies. The 5 percent damped spectral accelerations were computed using the ground motion models used in the seismic hazard analysis. The target spectra with a damping ratio of 7 percent were computed using damping adjustment factors for CEUS earthquake motions described in Geomatrix (2004).

3.2 SPECTRALLY MATCHED ACCELERATION TIME HISTORIES

Three sets of acceleration time histories were created for each scenario earthquake. Each set consists of three orthogonal components of motion. The time histories were modified such that their response spectra matched the target spectra through a process know as spectral matching. The procedure recommended in McGuire et al. (2001, Section 5.3) was used to develop the spectrally matched time histories. The matching procedure consists of the following components:

- Use a minimum of 100 frequencies per frequency decade.
- Match the response spectrum for a damping ratio of 5 percent.
- Specify both a minimum (0.9) and a maximum (1.3) criteria at each spectral frequency.
- Require that no more than nine adjacent spectral points fall below the target spectrum.

McGuire et al. (2001) state that the use of this procedure should prevent gaps in the power spectral density function for the scaled time histories. Spectral matching was performed using the time-domain spectral matching procedure proposed by Lilhanand and Tseng (1988) and later modified by Abrahamson (1992). This time-domain approach defines small adjustment time histories that are used to make nonstationary modifications to the original time history. This process preserves the nonstationary properties of the original time history. The time-domain approach can therefore develop a time history that matches a target spectrum yet still has a realistic displacement waveform.

The seed time histories were selected based on the seismological properties and the spectral shape of both horizontal and vertical components. The selected time histories for the 1 Hz target are the 1992 Landers earthquake, SER station, and the 1999 Chi-Chi earthquake, TAP067 and TAP075 stations. The selected time histories for the 10 Hz target are the 1987 Whittier Narrows earthquake, A-GRV station, the 1988 Saguenay earthquake, 1125S08 station, and the 1986 North Palm Springs earthquake, HCP station. All records were chosen from the CEUS record library provided in McGuire et al. (2001). Figures 6 and 7 compare the target spectra to the response spectra of the selected seed time histories. Tables 4 and 5 list the ground motion parameters and the seismological properties of the starting records. Figures 8 through 25 present plots of the acceleration, velocity, and displacement time histories for the selected seed time histories. It should be noted that these time histories have already been modified to some extent to transfer them from their recording environment to the CEUS tectonic environment. The starting records were first scaled to their corresponding target PGAs

before being spectrally matched. A comparison of the acceleration response spectra of the modified time histories to the target scenario earthquake spectrum, and plots of the acceleration, velocity, and displacement time histories, together with the normalized arias intensity for the horizontal and vertical components, are shown on Figures 26 through 79.

The PGAs, velocities, displacements, and durations of the spectrally matched time histories are summarized in Tables 6 and 7. Also included in Tables 6 and 7 are the ratios between peak velocities, displacements, and accelerations for the spectrally matched time histories, and a comparison with values recommended for the CEUS tectonic environment (McGuire et al., 2001). The recommended values for the 95th percentile scenario earthquake listed in Table 6 are those for rock site recordings in the largest magnitude (7 plus) and the largest distance bin (100 to 200 km) given in McGuire et al. (2001). The recommended values for the 95th percentile scenario earthquake listed in Table 7 are those for the magnitude of 6.0 and distance of 0 to 50 km rock site bin in McGuire et al. (2001).

The PGAs of the spectrally matched time histories and the PGA of the scenario earthquake target spectra are also compared in Tables 8 and 9. The differences are 8 percent or less .

4.0 SPECTRUM-COMPATIBLE ANALYSIS TOOLS

The modifications of time histories were made in time domain using program RSPMATCH (Abrahamson, 1993). The seed time histories were modified to be ”tightly matched” with the target response spectra.

The program SPECTRAE (Geomatrix, 2005) was used to compute 5 and 7 percent acceleration response spectra, and the program POLBASE (Dr. N. Abrahamson, personal communication, 1993) was used to perform a baseline correction to remove the numerical drift obtained during the time history matching process.

5.0 REFERENCES

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TABLES

TABLE 1

MEAN 2,475-YEAR UHRS (AT 5% DAMPING)
KINGSTON FOSSIL PLANT SITE
Roane County, Tennessee

Frequency (Hz)	Spectral Acceleration (g)
0.25	0.0187
0.5	0.0381
1.0	0.0543
2.5	0.1058
5	0.1563
10	0.2101
25	0.3007
33.3	0.3001
50	0.2674
100 (PGA)	0.1144

TABLE 2

TARGET SPECTRA AT 1 HZ OF SCENARIO EARTHQUAKE, M 7.6 AT 435 KM

KINGSTON FOSSIL PLANT SITE

Roane County, Tennessee

Frequency (Hz)	Scenario Earthquake, 5% Damped		Scenario Earthquake, 7% Damped	
	Horizontal Sa (g)	Vertical Sa (g)	Horizontal Sa (g)	Vertical Sa (g)
0.10[1]	0.0025	0.0020	0.0023	0.0019
0.13[1]	0.0040	0.0032	0.0036	0.0030
0.20[1]	0.0071	0.0057	0.0064	0.0053
0.25	0.0094	0.0075	0.0085	0.0069
0.50	0.0198	0.0159	0.0178	0.0144
1.00	0.0314	0.0251	0.0282	0.0225
2.50	0.0554	0.0444	0.0495	0.0394
5.00	0.0653	0.0523	0.0579	0.0464
10.00	0.0660	0.0528	0.0584	0.0469
25.00	0.0629	0.0503	0.0557	0.0448
33.33	0.0628	0.0502	0.0559	0.0447
50.00	0.0584	0.0467	0.0531	0.0416
100.00	0.0329	0.0264	0.0329	0.0264

[1] Extended frequencies based on ground motion model for spectral shape at long period for CEUS from NUREG/CR-6728

TABLE 3

TARGET SPECTRA AT 10 HZ OF SCENARIO EARTHQUAKE, M 6 AT 36 KM
KINGSTON FOSSIL PLANT SITE
Roane County, Tennessee

Frequency (Hz)	Scenario Earthquake, 5% Damped		Scenario Earthquake, 7% Damped	
	Horizontal Sa (g)	Vertical Sa (g)	Horizontal Sa (g)	Vertical Sa (g)
0.10[1]	0.0007	0.0006	0.0007	0.0006
0.13[1]	0.0014	0.0011	0.0013	0.0010
0.20[1]	0.0029	0.0023	0.0027	0.0022
0.25	0.0043	0.0034	0.0040	0.0032
0.50	0.0138	0.0111	0.0127	0.0101
1.00	0.0308	0.0247	0.0278	0.0221
2.50	0.0825	0.0660	0.0736	0.0587
5.00	0.1464	0.1171	0.1298	0.1039
10.00	0.2101	0.1681	0.1858	0.1493
25.00	0.2816	0.2253	0.2496	0.2007
33.33	0.2865	0.2292	0.2553	0.2039
50.00	0.2634	0.2107	0.2396	0.1874
100.00	0.1058	0.0847	0.1058	0.0847

[1] Extended frequencies based on ground motion model for spectral shape at long period for CEUS from NUREG/CR-6728

TABLE 4

SEED TIME HISTORY RECORDINGS USED FOR SCALING TO 1 HZ SCENARIO EARTHQUAKE SPECTRA
KINGSTON FOSSIL PLANT SITE
Roane County, Tennessee

Earthquake	Date	Magnitude	Station	Distance (km)	Component	Filter Corners HP (Hz)	Filter Corners LP (Hz)	Record Parameters* PGA (g)	Record Parameters* PGV (cm/s)	Record Parameters* PGD (cm)	Record Parameters* Duration** (sec)
Landers	6/28/1992	7.3	Amboy	69.2	SER000	0.2	25	0.103	6.3	1.71	29.8
					SER270	0.11	25	0.095	8.6	6.85	31.7
					SER-UP	0.18	25	0.121	8.9	3.32	26.7
Chi-Chi, Taiwan	9/20/1999	7.6	TAP075	118.4	TAP075-V	0.03	30	0.11	10.8	9.85	28.2
					TAP075-N	0.02	50	0.171	11.1	4.74	24.9
					TAP075-W	0.01	30	0.205	11.4	5.38	24.9
Chi-Chi, Taiwan	9/20/1999	7.6	TAP067	94.7	TAP067-N	0.03	20	0.114	13.9	12.64	40.8
					TAP067-W	0.02	20	0.091	11	5.63	39.3
					TAP067-V	0.02	20	0.089	12	7.39	38.2

* After being modified for CEUS tectonic environment by McGuire et al. (2001)
** Duration is defined as the time for cumulative energy to grow from 5% to 75% of its total value.

TABLE 5

SEED TIME HISTORY RECORDINGS USED FOR SCALING TO 10 HZ SCENARIO EARTHQUAKE SPECTRA
KINGSTON FOSSIL PLANT SITE
Roane County, Tennessee

Earthquake	Date	Magnitude	Station	Distance (km)	Component	Filter Corners		Record Parameters*			
						HP (Hz)	LP (Hz)	PGA (g)	PGV (cm/s)	PGD (cm)	Duration** (sec)
Whittier Narrows	10/1/1987	6.0	Garvey Res.—Control Bldg.	12.1	A-GRV-UP	0.7	40	0.844	14	1.04	2.4
					A-GRV060	0.15	40	0.556	15.1	1.56	3.3
					A-GRV330	0.2	40	0.796	17.9	2.2	2.4
Saguenay	11/25/1988	5.9	GSC Site 8—La Malbaie	97.5	1125S08V	0.2	30	0.066	1.7	0.12	22.7
					1125S08L	0.25	0	0.134	4.6	0.48	10.4
					1125S08T	0.25	30	0.058	1.4	0.13	21
N. Palm Springs	07/08/1986	6.0	Hurkey Creek Park	34.9	HCP-UP	0.4	50	0.192	5	0.74	5.4
					HCP045	0.6	50	0.509	6.5	0.44	6.8
					HCP135	0.5	50	0.292	8.1	0.7	6.5

* After being modified for CEUS tectonic environment by McGuire et al. (2001)
** Duration is defined as the time for cumulative energy to grow from 5% to 75% of its total value.

TABLE 6

GROUND MOTION PARAMETERS FOR SPECTRALLY MATCHED TIME HISTORIES AT 1 HZ
KINGSTON FOSSIL PLANT SITE
Roane County, Tennessee

Set	Mag. (M)	R (km)	Comp.	Spectrally-Matched from	PGA (g)	PGV (cm/sec)	PGD (cm)	PGV/PGA (cm/sec/g)		PGA*PGD/PGV^2		Duration (sec) **	
								Spectrally Matched Time Histories	NUREG CR-6728 5%–95%	Spectrally Matched Time Histories	NUREG CR-6728 5%–95%	Spectrally Matched Time Histories	NUREG*** CR-6728
1	7.6	435	H1	SER000	0.034	2.89	1.70	85.00	33.46–157.08*	0.007	3.20–11.53*	40.36	11.7–26.3*
			H2	SER270	0.034	3.59	1.72	105.59		0.005		35.88	
			VT	SER-UP	0.027	1.96	1.56	72.59		0.011		43.04	
2	7.6	435	H1	TPA075-N	0.034	3.73	2.19	109.71	33.46–157.08*	0.005	3.20–11.53*	33.62	11.7–26.3*
			H2	TPA075-W	0.035	2.89	1.97	82.57		0.008		40.77	
			VT	TPA075-V	0.027	2.29	1.61	84.81		0.008		45.12	
3	7.6	435	H1	TAP067-N	0.035	3.02	2.00	86.29	33.46–157.08*	0.008	3.20–11.53*	53.66	11.7–26.3*
			H2	TAP067-W	0.035	2.98	2.48	85.14		0.010		52.87	
			VT	TAP067-V	0.028	2.39	2.05	85.36		0.010		56.01	

* Values for bin of M 7+ and distance 100–200 km
** Duration is defined as the time for cumulative energy to grow from 5% to 95% of its total value.
*** Duration ranges are taken as ± 50% (log additions) of the expected median values evaluated at the average (log) bin distance interval for given magnitude and distance bins.

TABLE 7

GROUND MOTION PARAMETERS FOR SPECTRALLY MATCHED TIME HISTORIES AT 10 HZ
KINGSTON FOSSIL PLANT SITE
Roane County, Tennessee

Set	Mag. (M)	R (km)	Comp.	Spectrally-Matched from	PGA (g)	PGV (cm/sec)	PGD (cm)	PGV/PGA (cm/sec/g)		PGA*PGD/PGV^2		Duration (sec) **	
								Spectrally Matched Time Histories	NUREG CR-6728 5%–95%	Spectrally Matched Time Histories	NUREG CR-6728 5%–95%	Spectrally Matched Time Histories	NUREG*** CR-6728
1	6	36	H1	A-GRV060	0.114	4.40	1.22	38.60	12.66–48.80*	0.007	2.05–4.99*	6.41	1.1–3.6*
			H2	A-GRV330	0.110	2.91	1.05	26.45		0.014		5.24	
			VT	A-GRV-UP	0.087	2.10	1.18	23.10		0.025		7.18	
2	6	36	H1	1125S08T	0.111	3.18	0.92	28.65	12.66–48.80**	0.010	2.05–4.99*	8.94	1.1–3.6*
			H2	1125S08L	0.111	3.52	1.16	31.71		0.010		12.41	
			VT	1125S08V	0.088	2.52	1.15	28.64		0.016		10.65	
3	6	36	H1	HCP045	0.113	3.55	0.90	31.42	12.66–48.80**	0.008	2.05–4.99*	8.09	1.1–3.6*
			H2	HCP135	0.112	3.53	0.68	31.52		0.006		8.45	
			VT	HCP-UP	0.089	3.00	0.73	33.71		0.007		8.41	

* Values for bin of M 5–6 and distance 0–50 km
** Duration is defined as the time for cumulative energy to grow from 5% to 95% of its total value.
*** Duration ranges are taken as ± 50% (log additions) of the expected median values evaluated at the average (log) bin distance interval for given magnitude and distance bins.

TABLE 8

PEAK GROUND ACCELERATIONS OF SPECTRALLY MATCHED TIME HISTORIES – 1 HZ

KINGSTON FOSSIL PLANT SITE

Roane County, Tennessee

Set	Component	PGA (g)	Target PGA (g)	Difference
1	H1	0.034	0.033	+3%
	H2	0.034	0.033	+3%
	VT	0.027	0.026	+4%
2	H1	0.034	0.033	+3%
	H2	0.035	0.033	+6%
	VT	0.027	0.026	+4%
3	H1	0.035	0.033	+6%
	H2	0.035	0.033	+6%
	VT	0.028	0.026	+8%

TABLE 9

PEAK GROUND ACCELERATIONS OF SPECTRALLY MATCHED TIME HISTORIES – 10 HZ

KINGSTON FOSSIL PLANT SITE
Roane County, Tennessee

Set	Component	PGA (g)	Target PGA (g)	Difference
1	H1	0.114	0.106	+8%
	H2	0.110	0.106	+4%
	VT	0.087	0.085	+2%
2	H1	0.111	0.106	+5%
	H2	0.111	0.106	+5%
	VT	0.088	0.085	+4%
3	H1	0.113	0.106	+7%
	H2	0.112	0.106	+6%
	VT	0.089	0.085	+5%

FIGURES

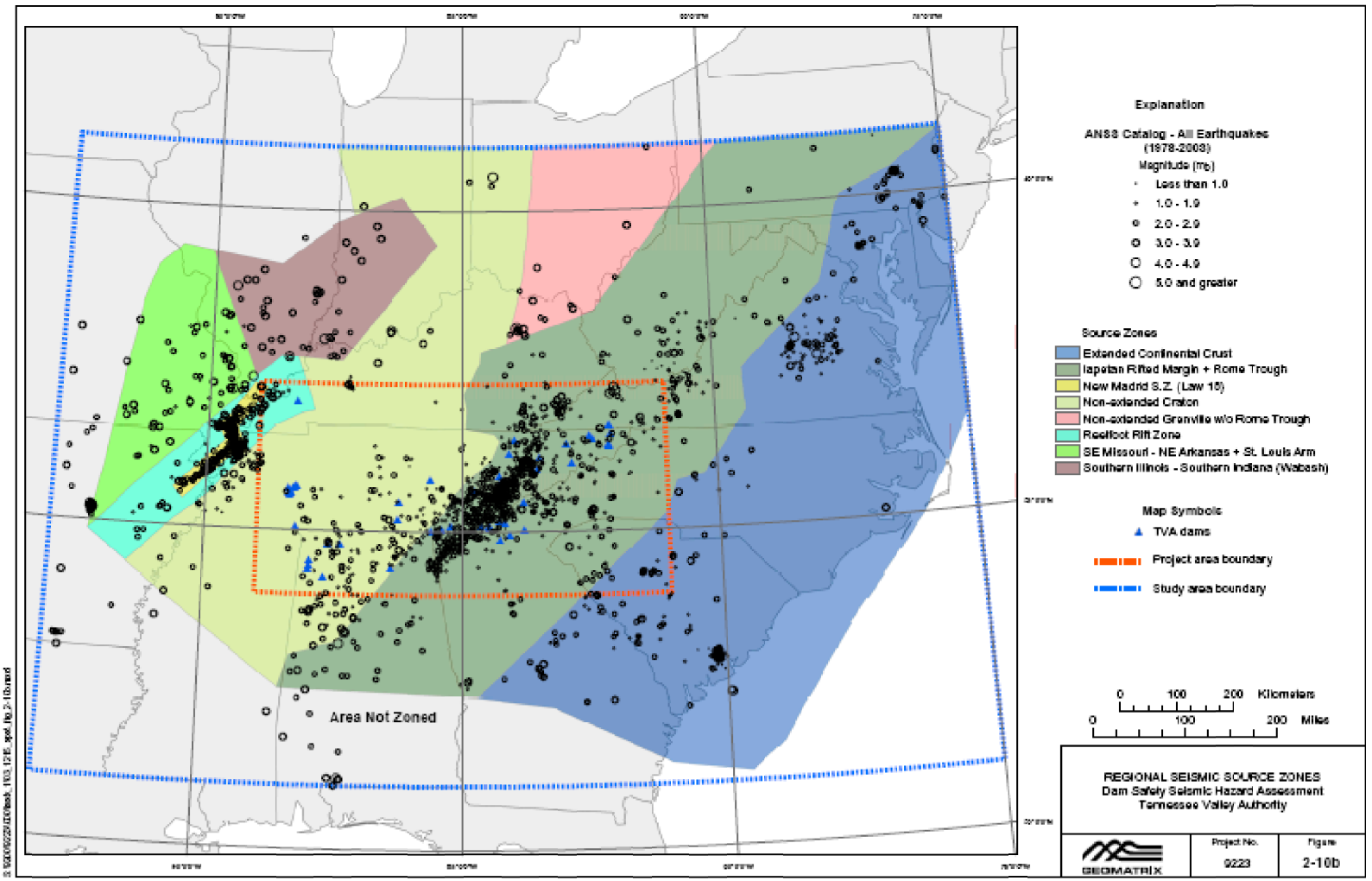
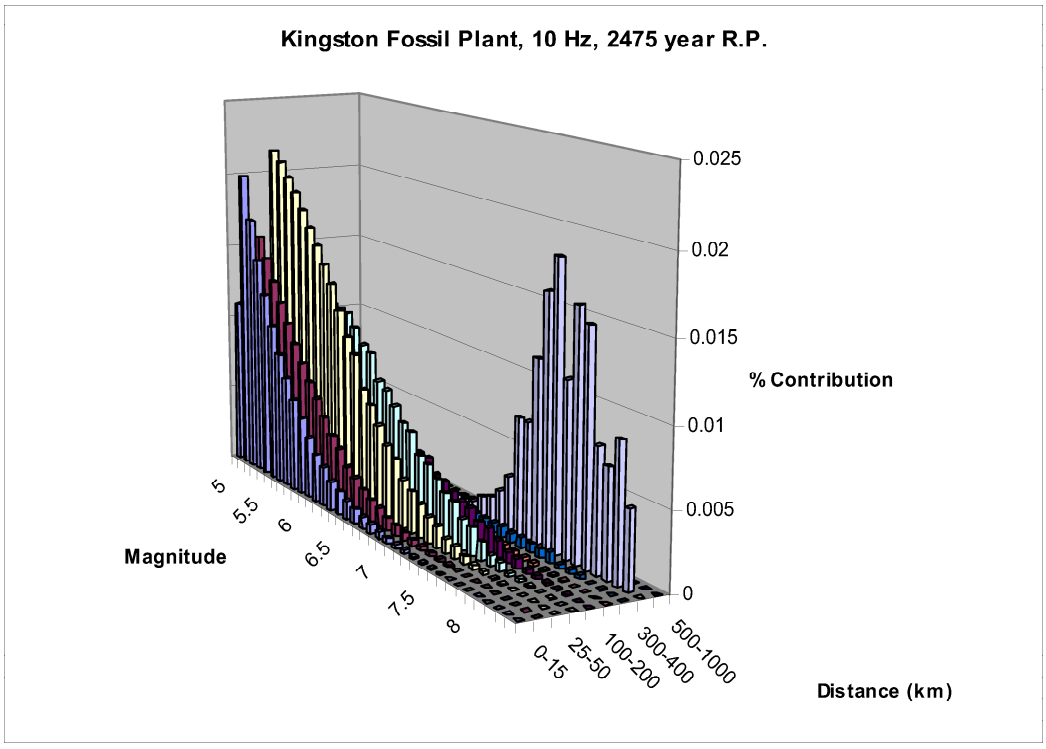


Figure 1: Regional seismic source zones in the TVA Dam Safety seismic hazard model. (Source: Geomatrix, 2004)



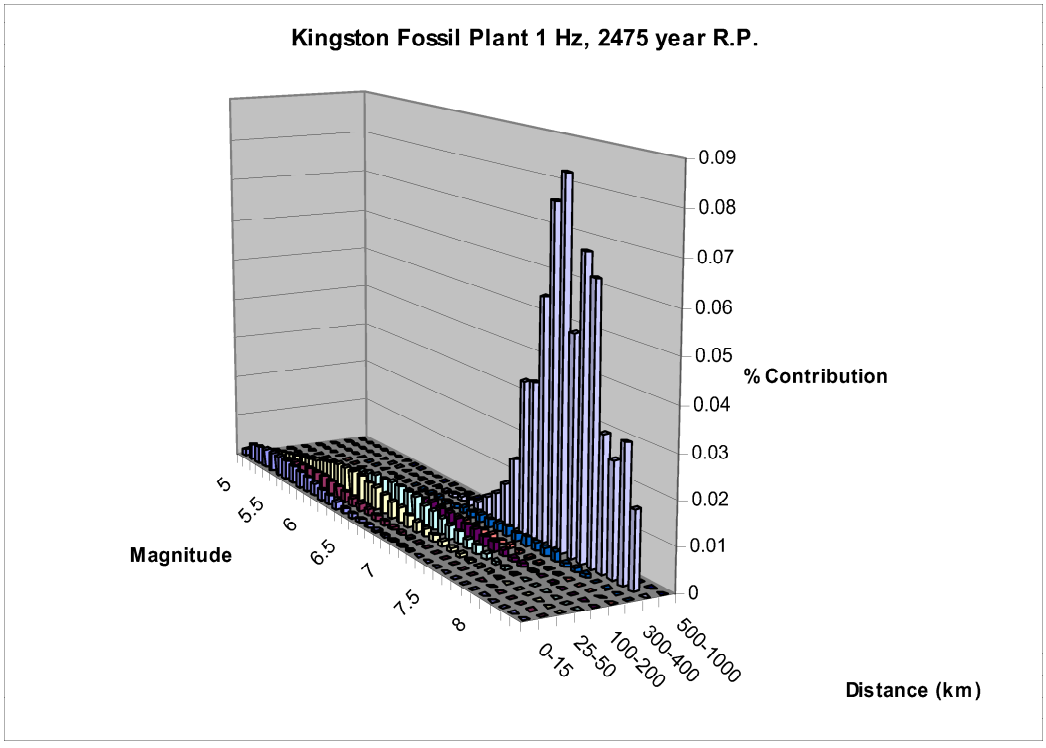


Figure 2: Deaggregation of the 2,475-Year Hazard for 10 Hz and 1 Hz Spectral Accelerations

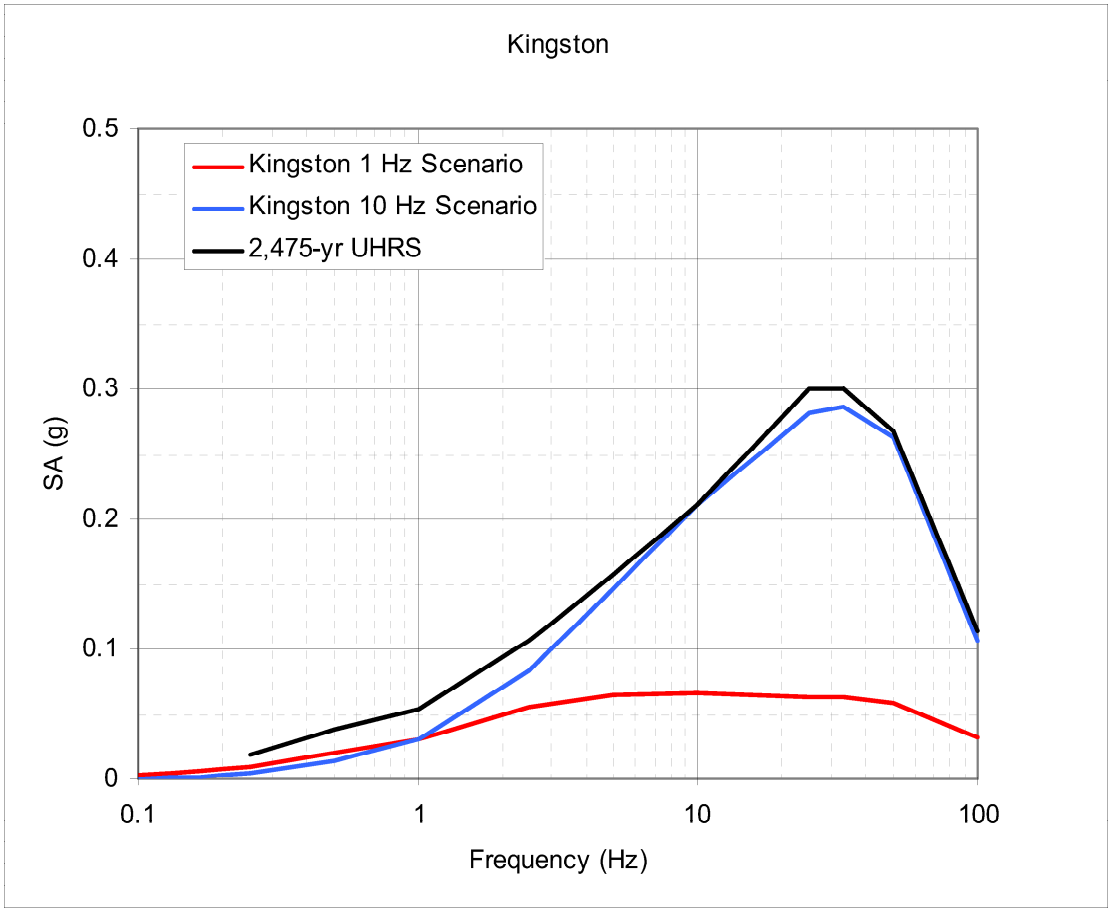
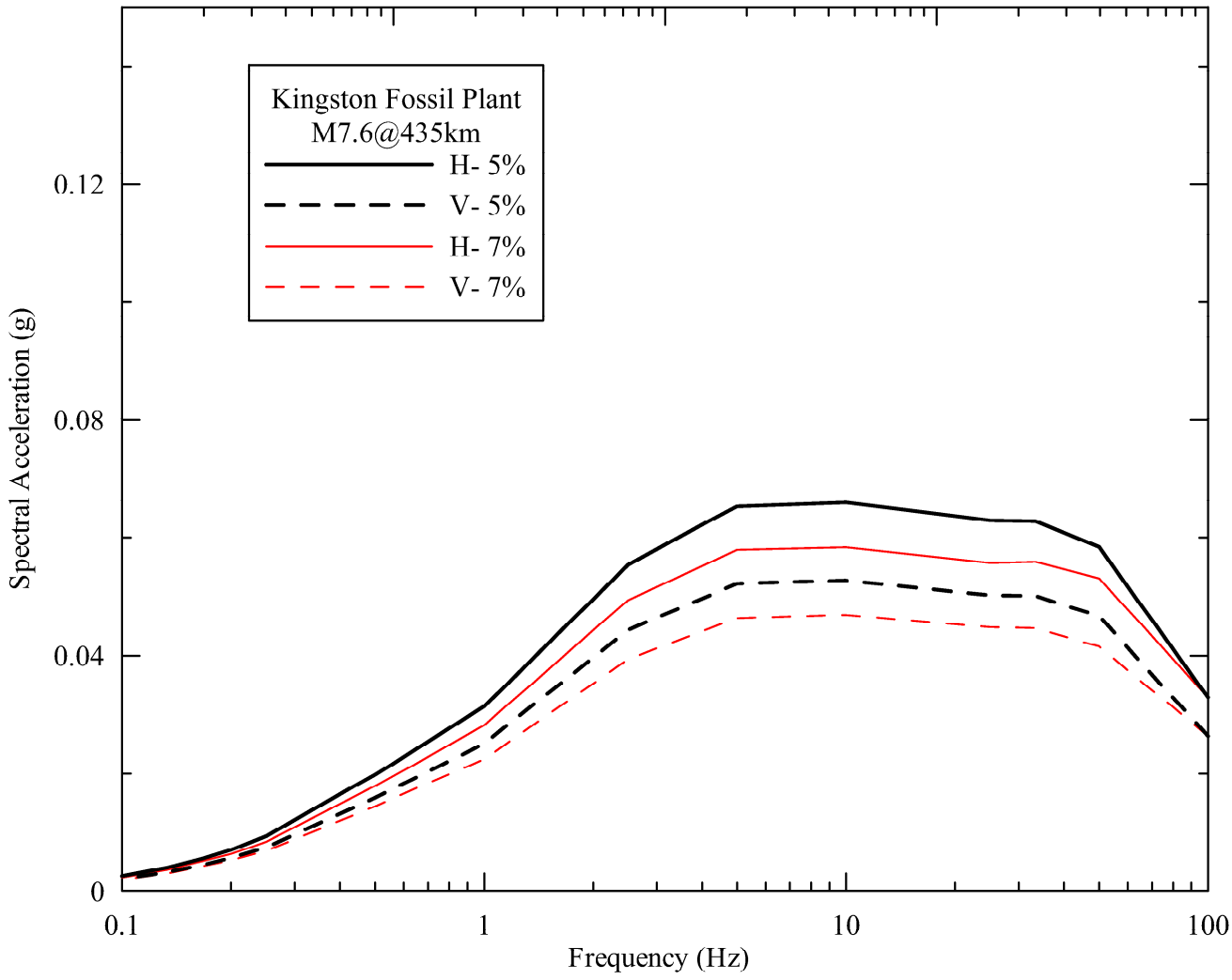


Figure 3: Comparison of 2,475-Year UHRS and Scenario Earthquake Spectra



Horizontal and Vertical Target Response Spectra (5% and 7% Damping) For the M7.6, 435 km Scenario Earthquake	AMEC Geomatrix
Project No: 13452.003	Figure 4

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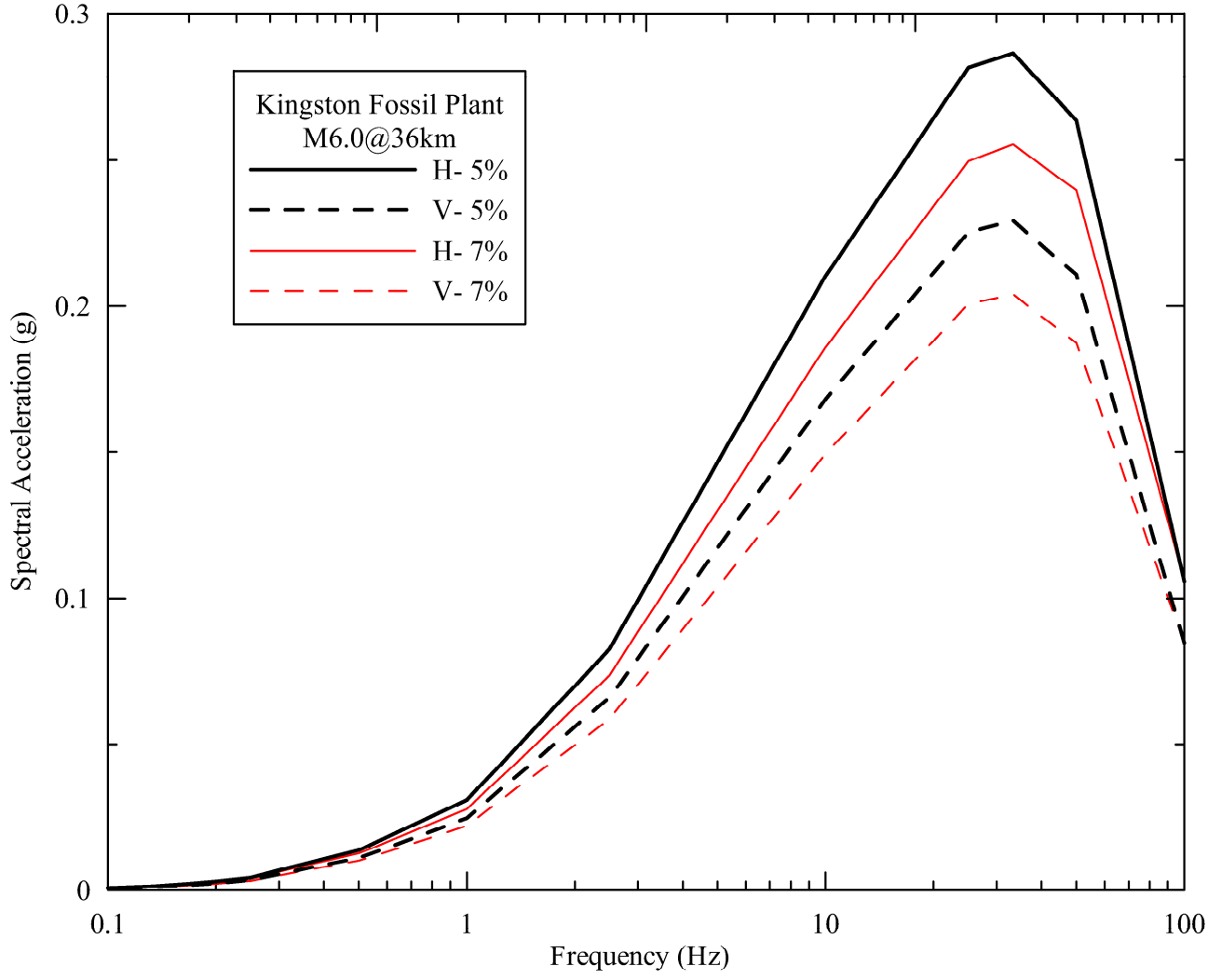

Horizontal and Vertical Target Response Spectra (5% and 7% Damping)
For the M6.0, 36 km Scenario Earthquake

AMEC Geomatrix

Project No: 13452.003

Figure 5

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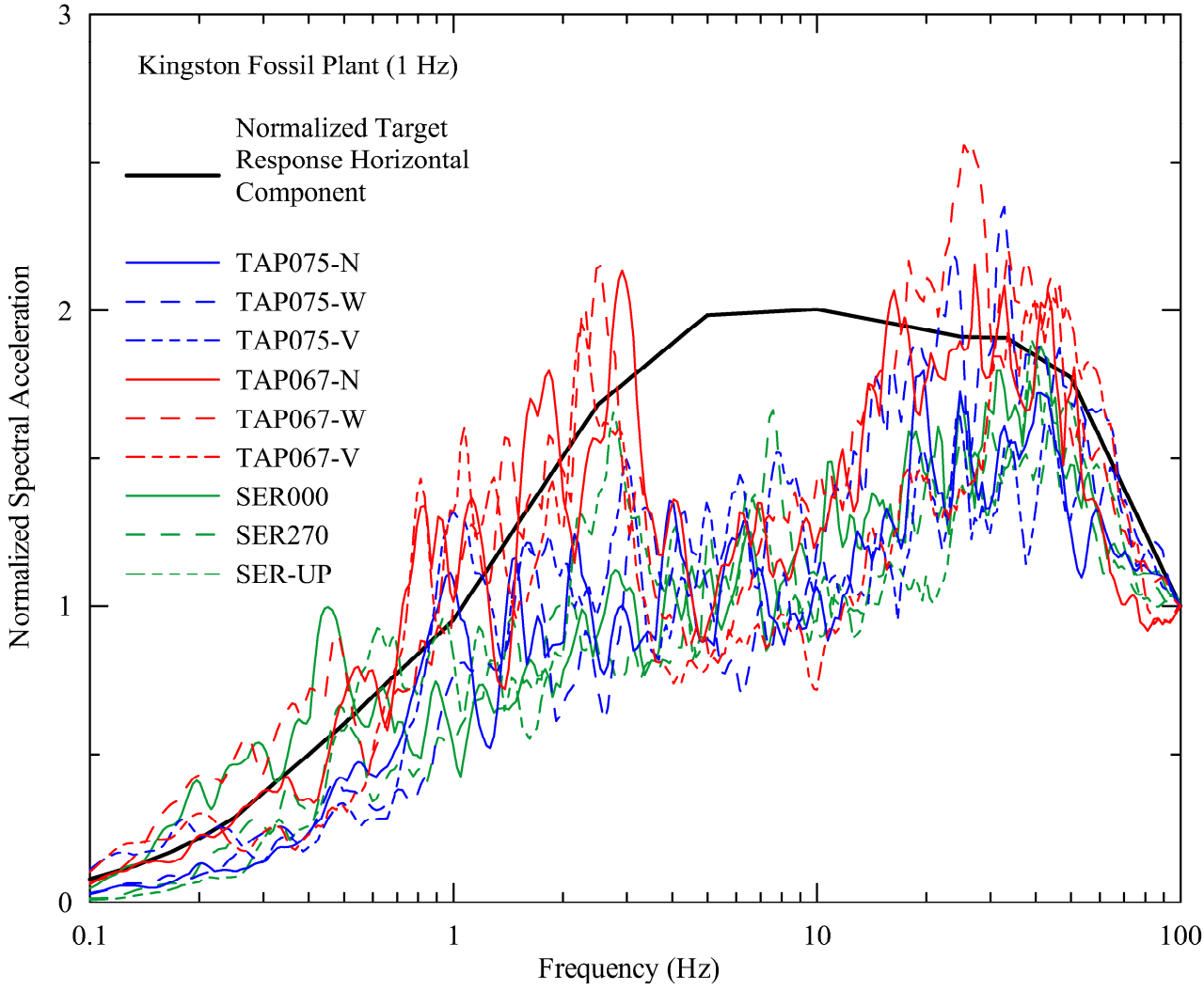

Comparison of Spectral Shape between normalized Horizontal 1 Hz Target Spectrum and the normalized Selected Seed Time Histories at 5% Damping

AMEC Geomatrix

Project No: 13452.003

Figure 6

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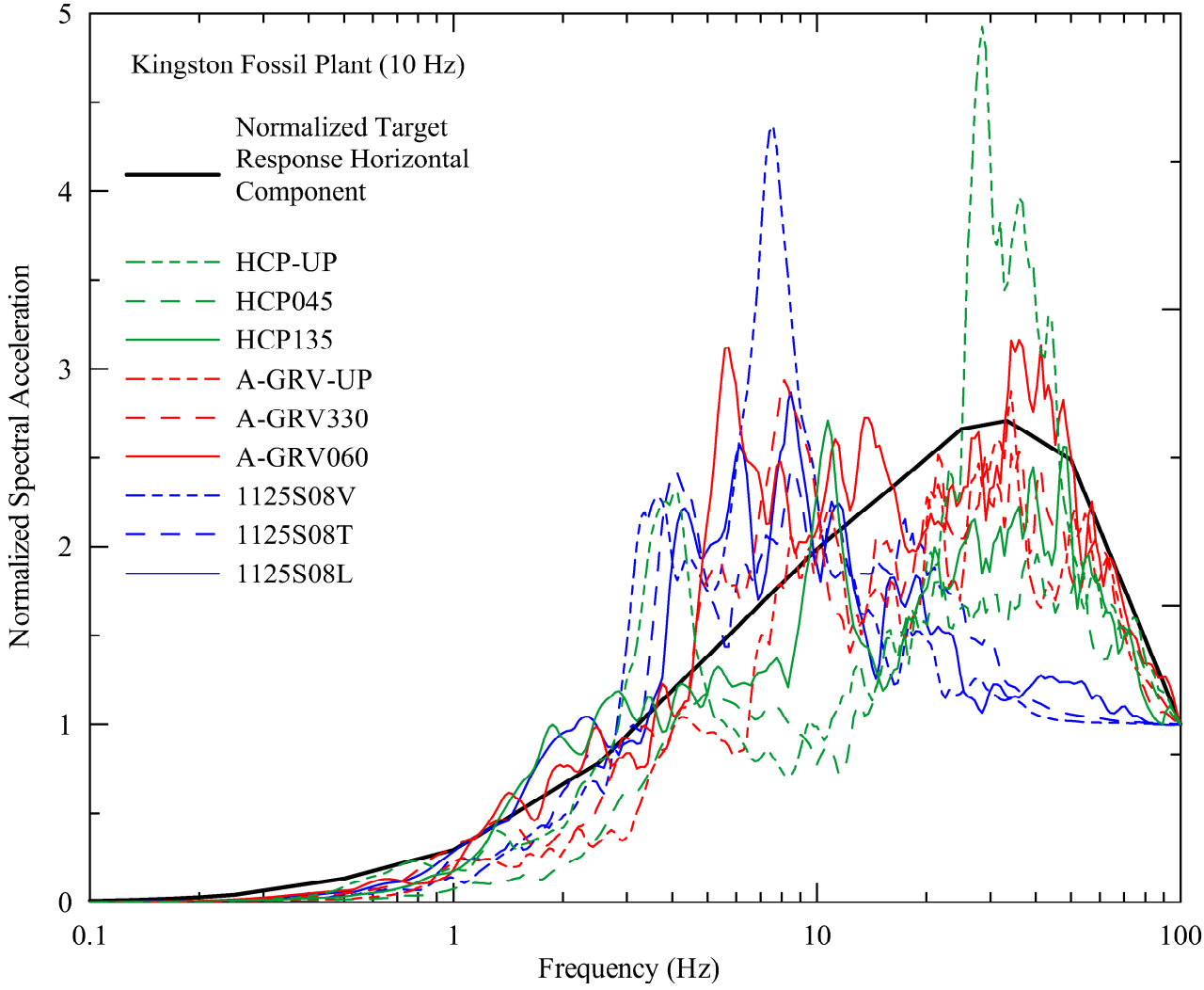

Comparison of Spectral Shape between normalized Horizontal 10 Hz Target Spectrum and the normalized Selected Seed Time Histories at 5% Damping	AMEC Geomatrix
Project No: 13452.003	Figure 7

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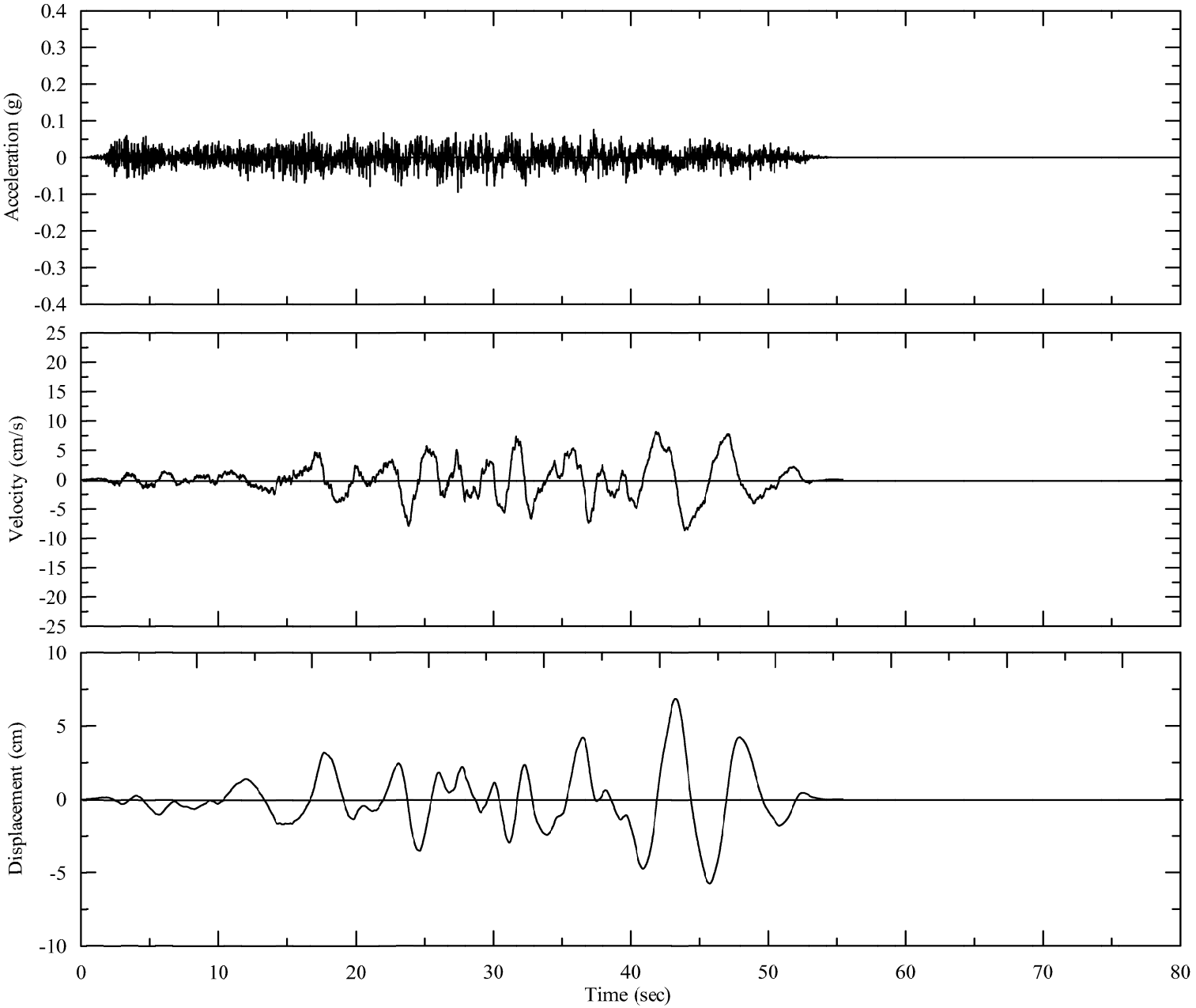

Acceleration, Velocity, and Displacement Time Histories Landers Earthquake,SER000 Station, Horizontal Component	AMEC Geomatrix
Project No. 13452.003	Figure 8

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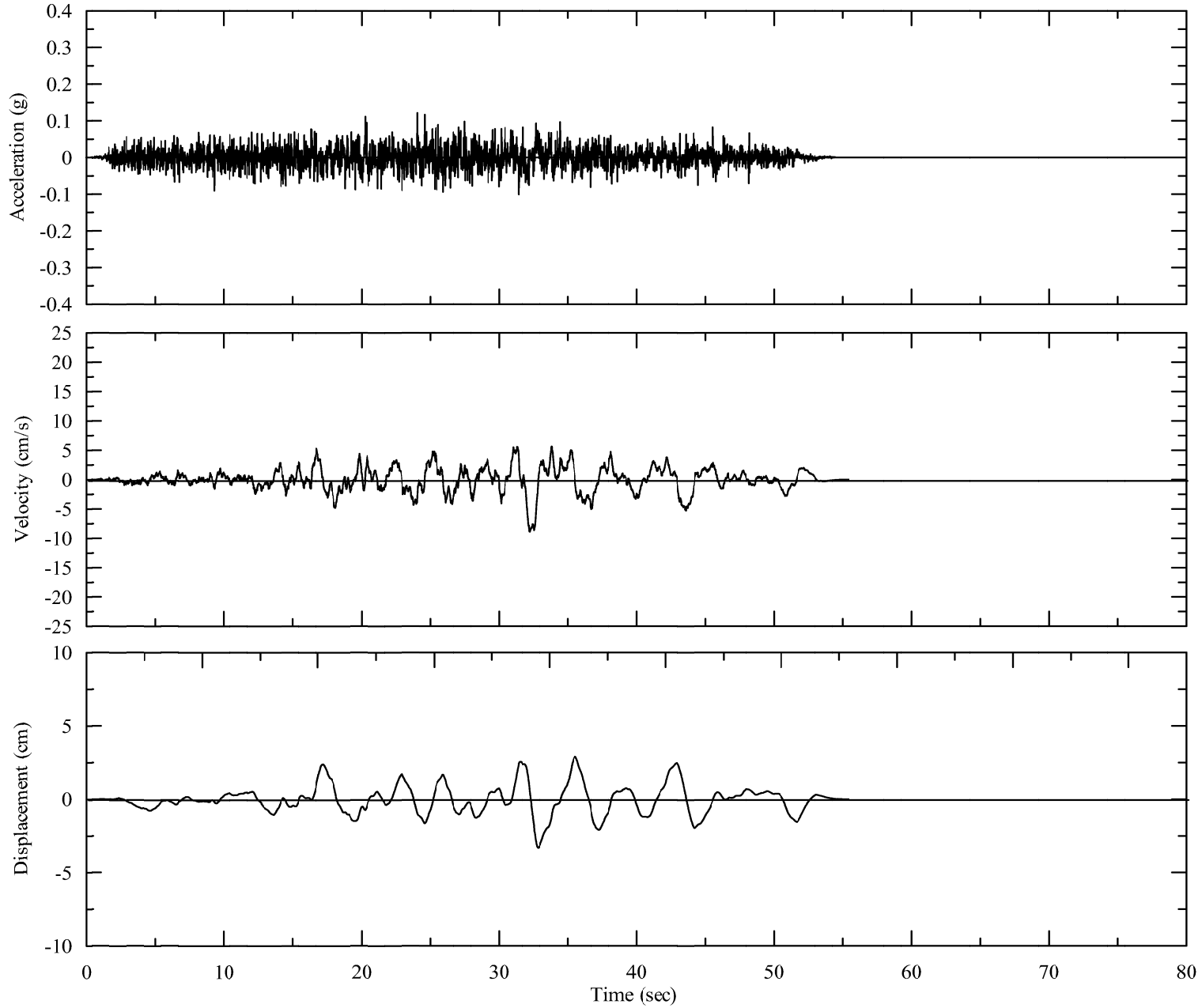

Acceleration, Velocity, and Displacement Time Histories Landers Earthquake,SER270 Station, Horizontal Component	AMEC Geomatrix
Project No. 13452.003	Figure 9

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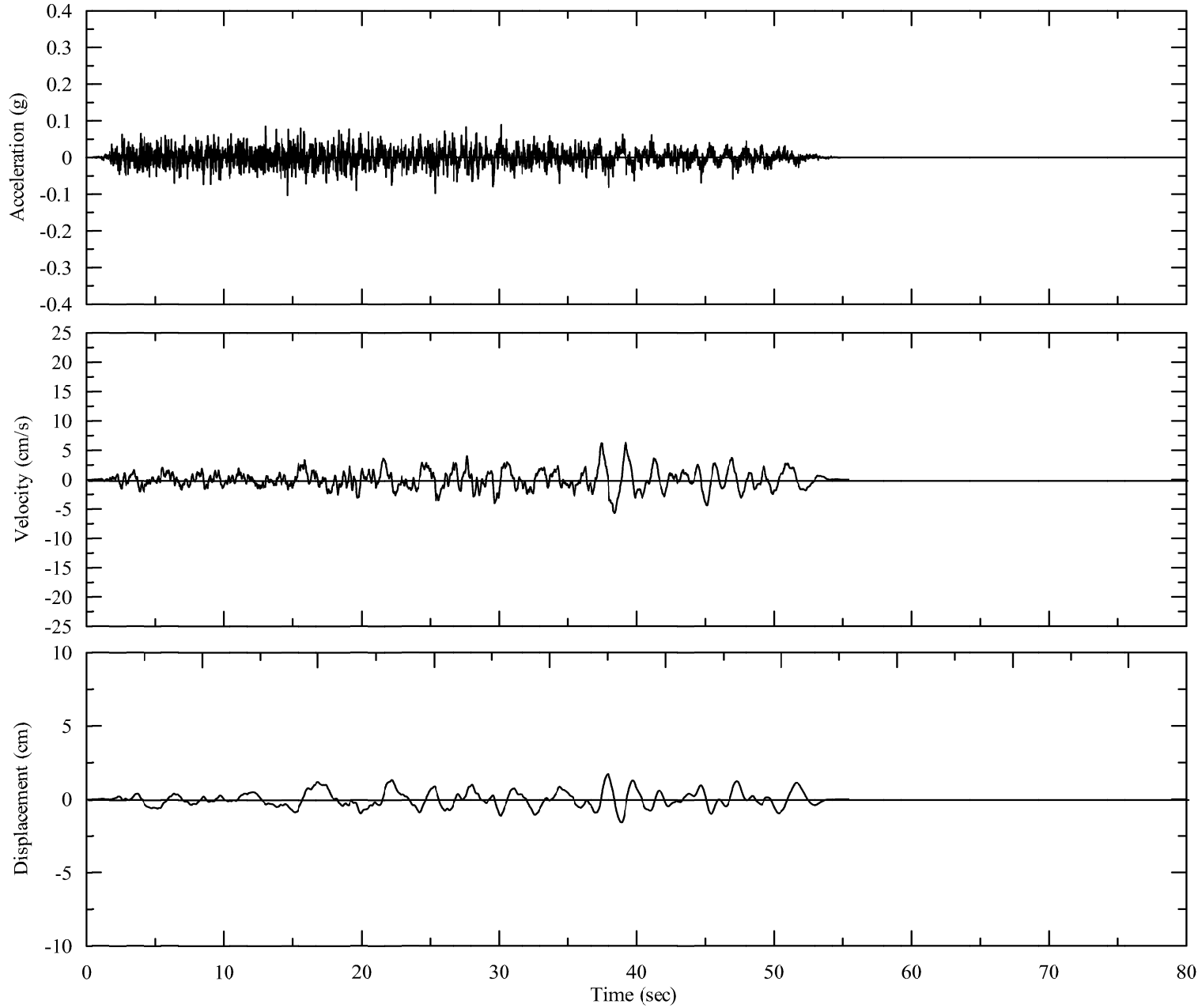

Acceleration, Velocity, and Displacement Time Histories Landers Earthquake,SER-UP Station, Vertical Component	AMEC Geomatrix
Project No. 13452.003	Figure 10

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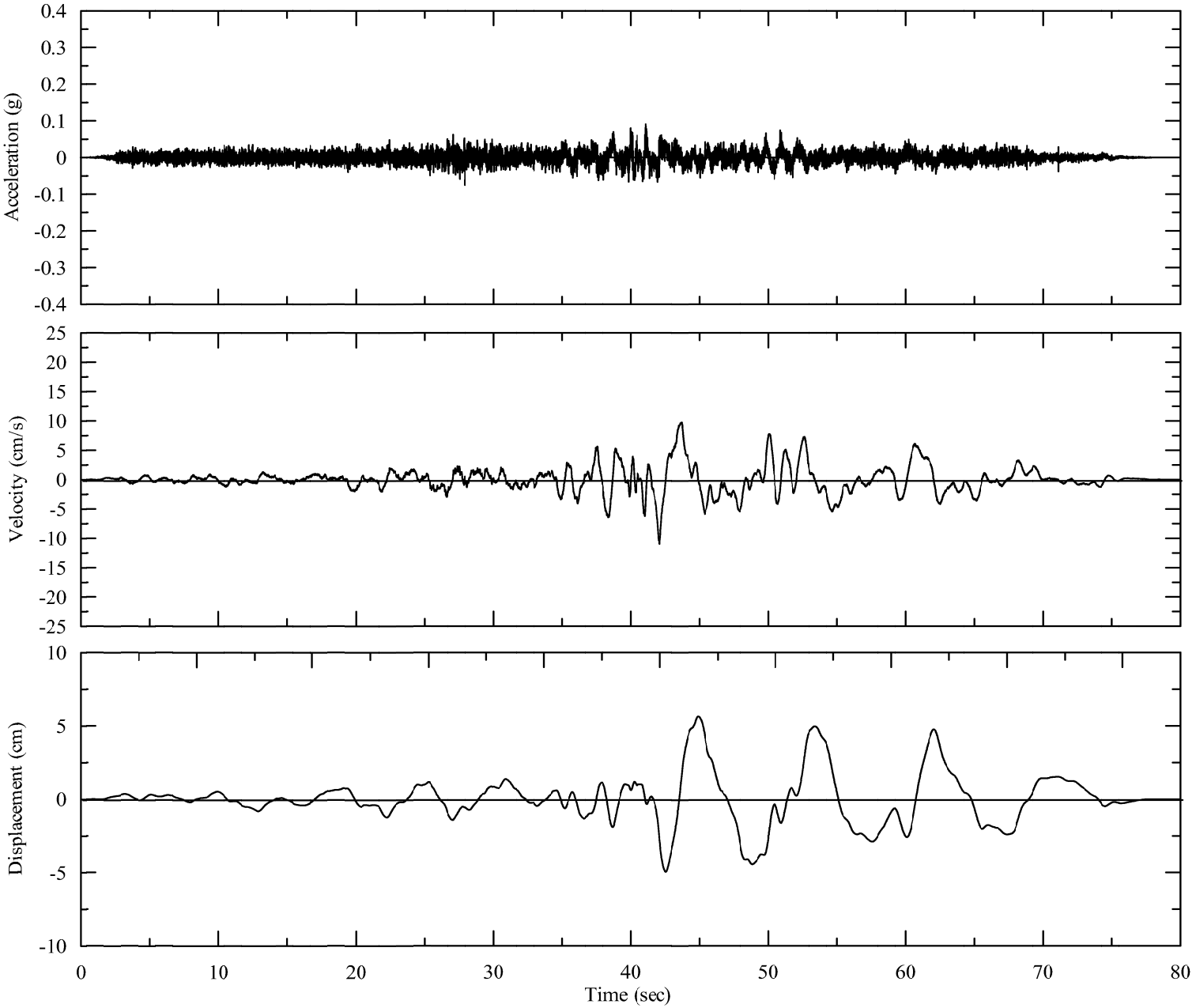

Acceleration, Velocity, and Displacement Time Histories 1999 Chi-Chi Earthquake, TAP067-N Station, North Component	AMEC Geomatrix
Project No. 13452.003	Figure 11

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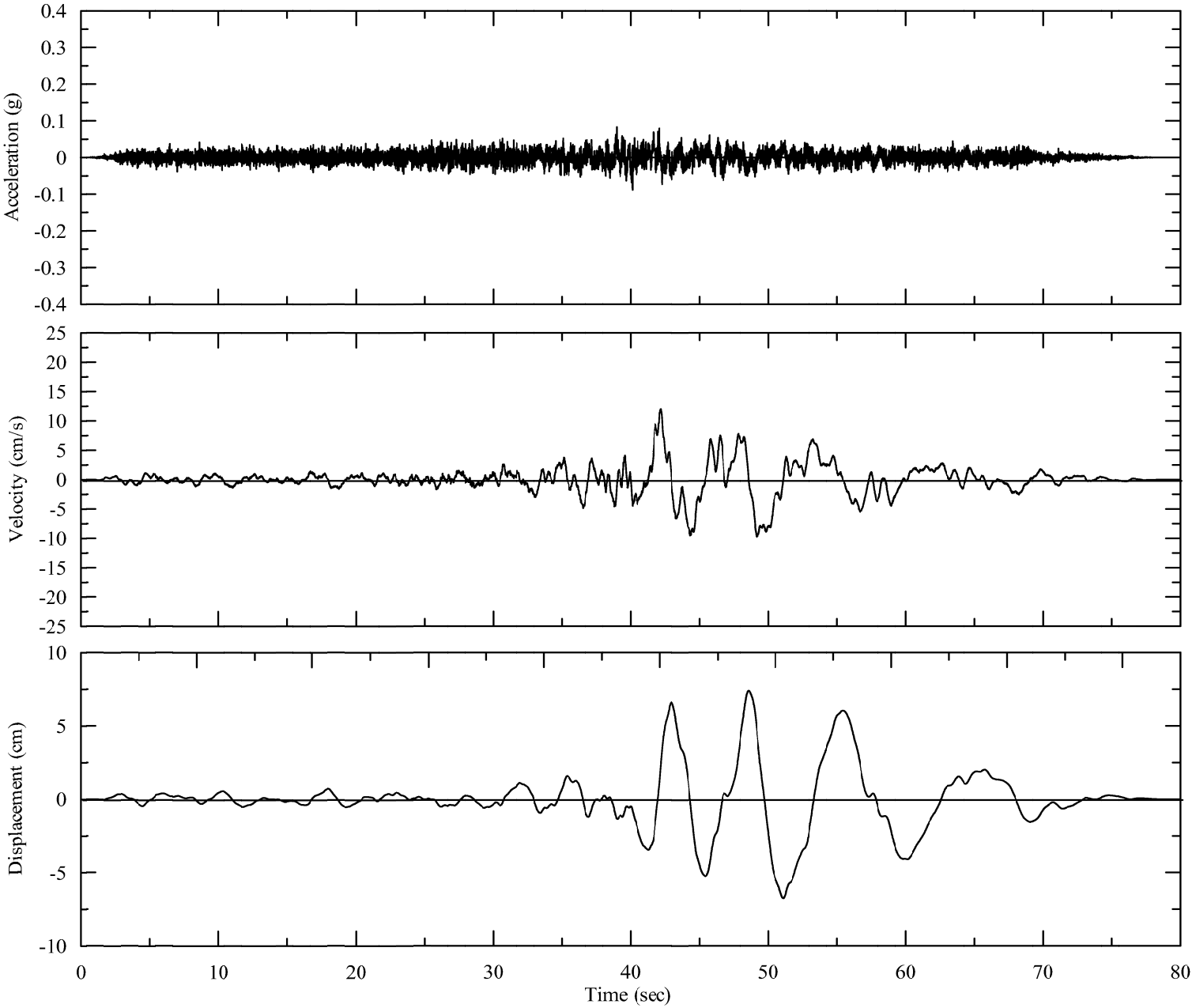

Acceleration, Velocity, and Displacement Time Histories 1999 Chi-Chi Earthquake, TAP067-W Station, West Component	AMEC Geomatrix
Project No. 13452.003	Figure 12

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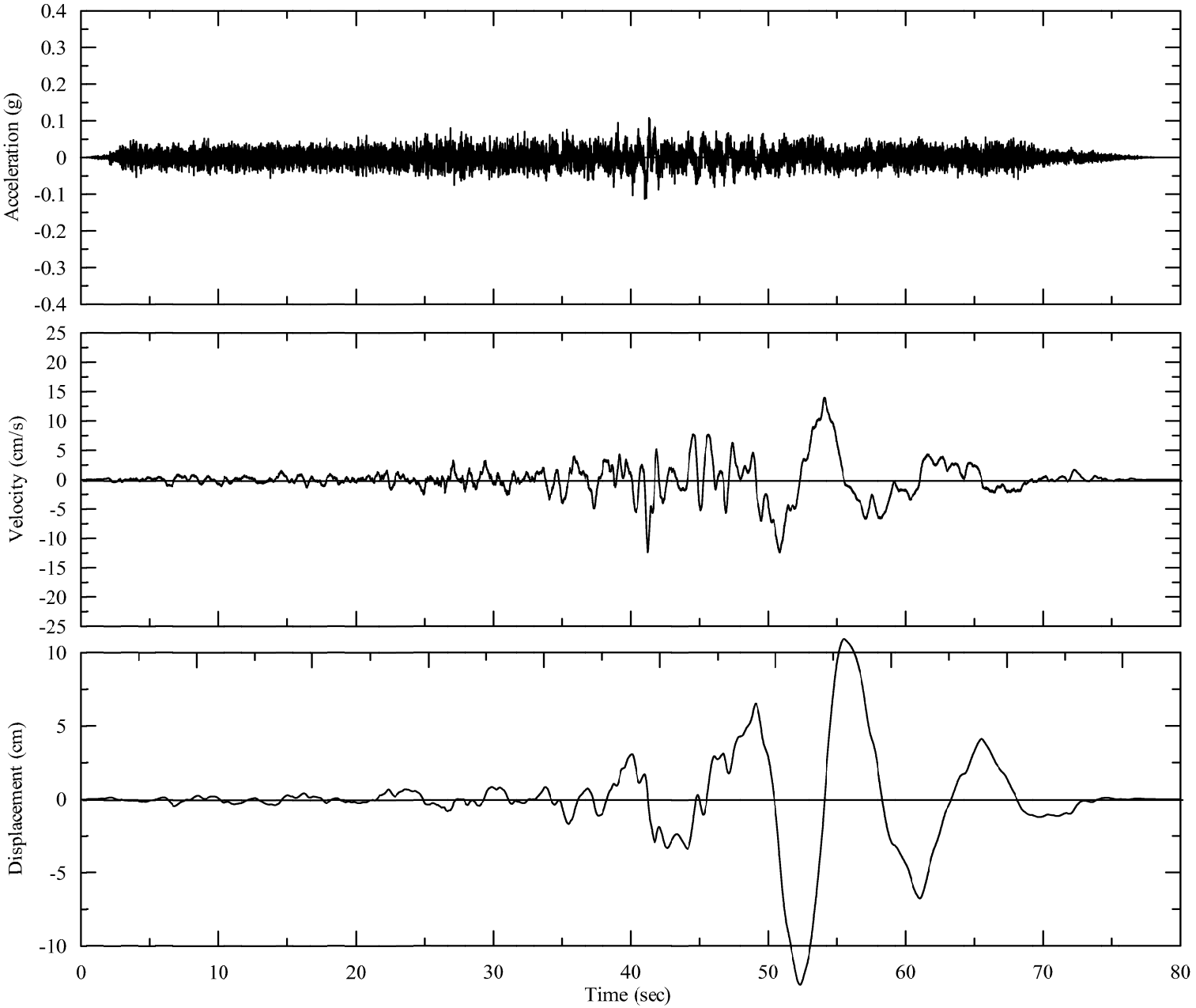

Acceleration, Velocity, and Displacement Time Histories 1999 Chi-Chi Earthquake, TAP067-V Station, Vertical Component	AMEC Geomatrix
Project No. 13452.003	Figure 13

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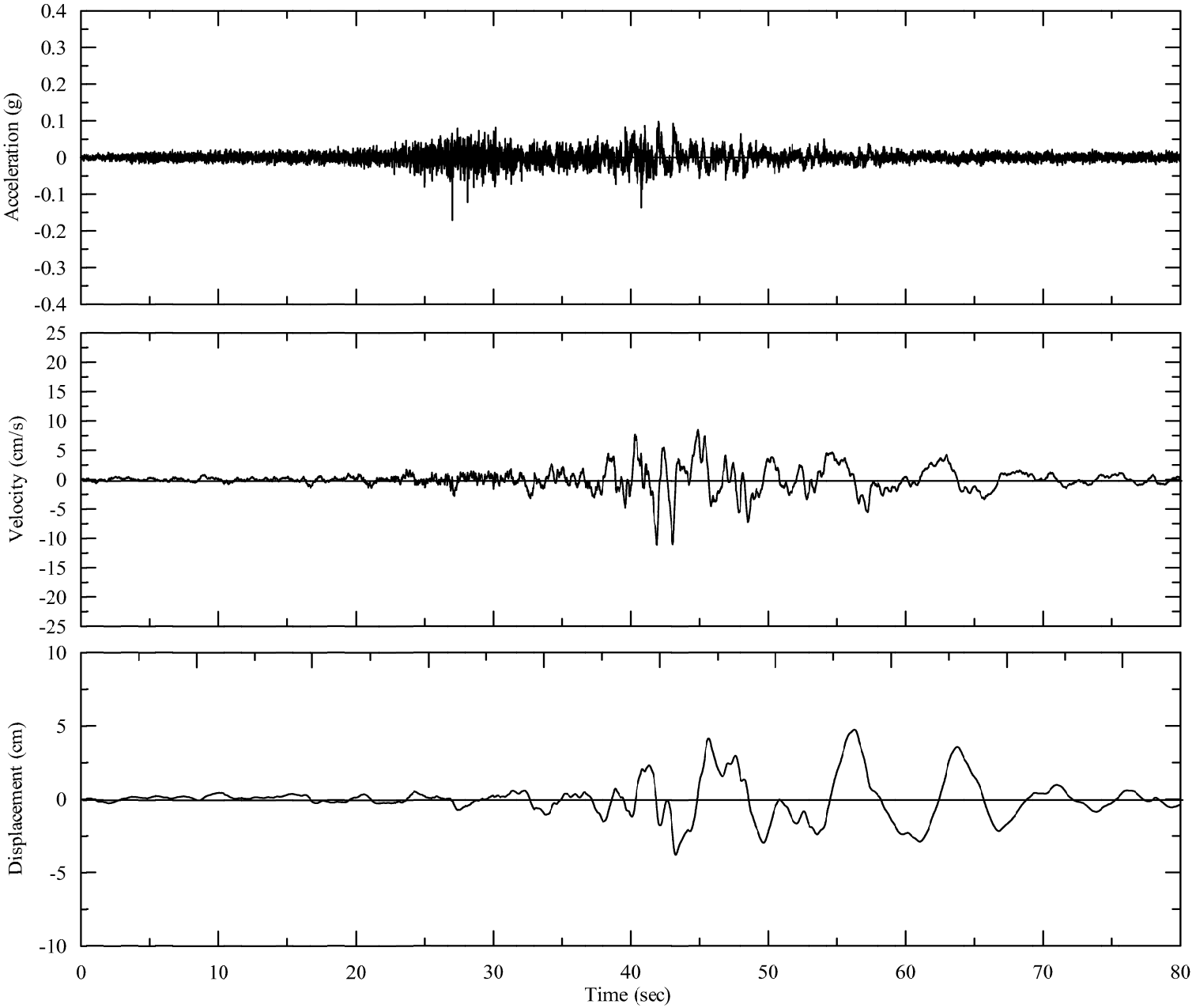

Acceleration, Velocity, and Displacement Time Histories Landers Earthquake, TAP075-N Station, Horizontal Component	AMEC Geomatrix
Project No. 13452.003	Figure 14

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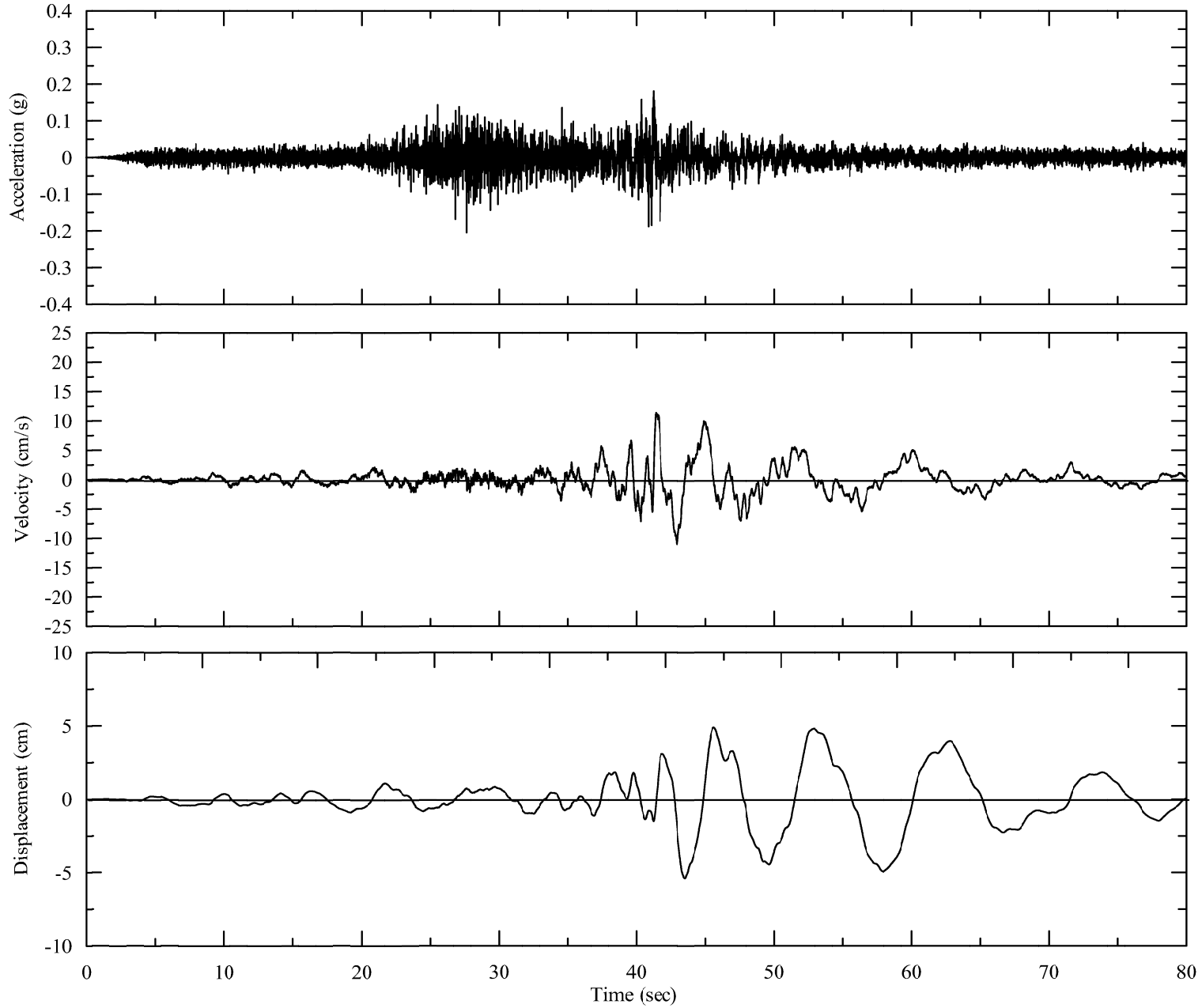

Acceleration, Velocity, and Displacement Time Histories Landers Earthquake, TAP075-W Station, Horizontal Component	AMEC Geomatrix
Project No. 13452.003	Figure 15

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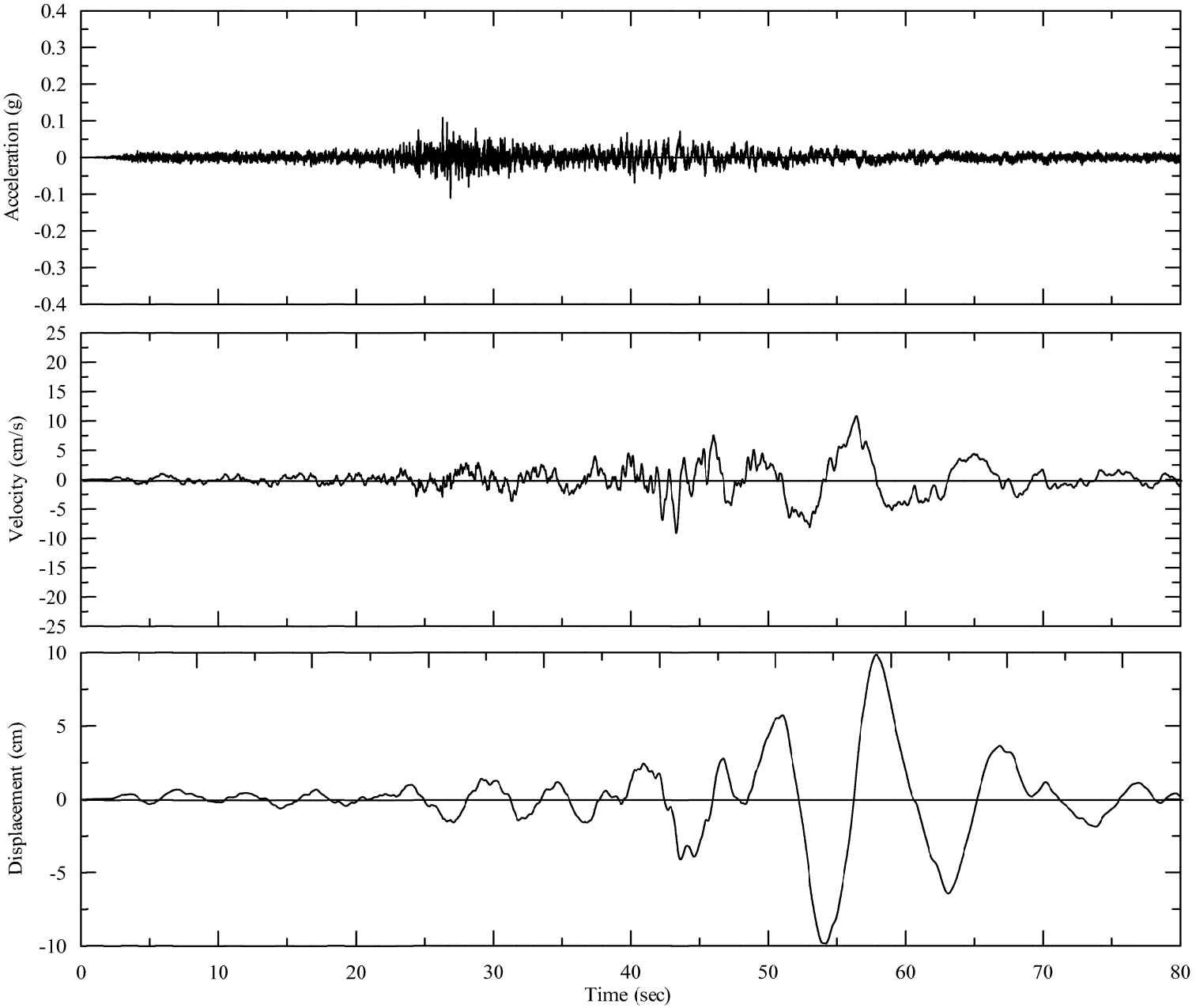

Acceleration, Velocity, and Displacement Time Histories Landers Earthquake, TAP075-V Station, Vertical Component	AMEC Geomatrix
Project No. 13452.003	Figure 16

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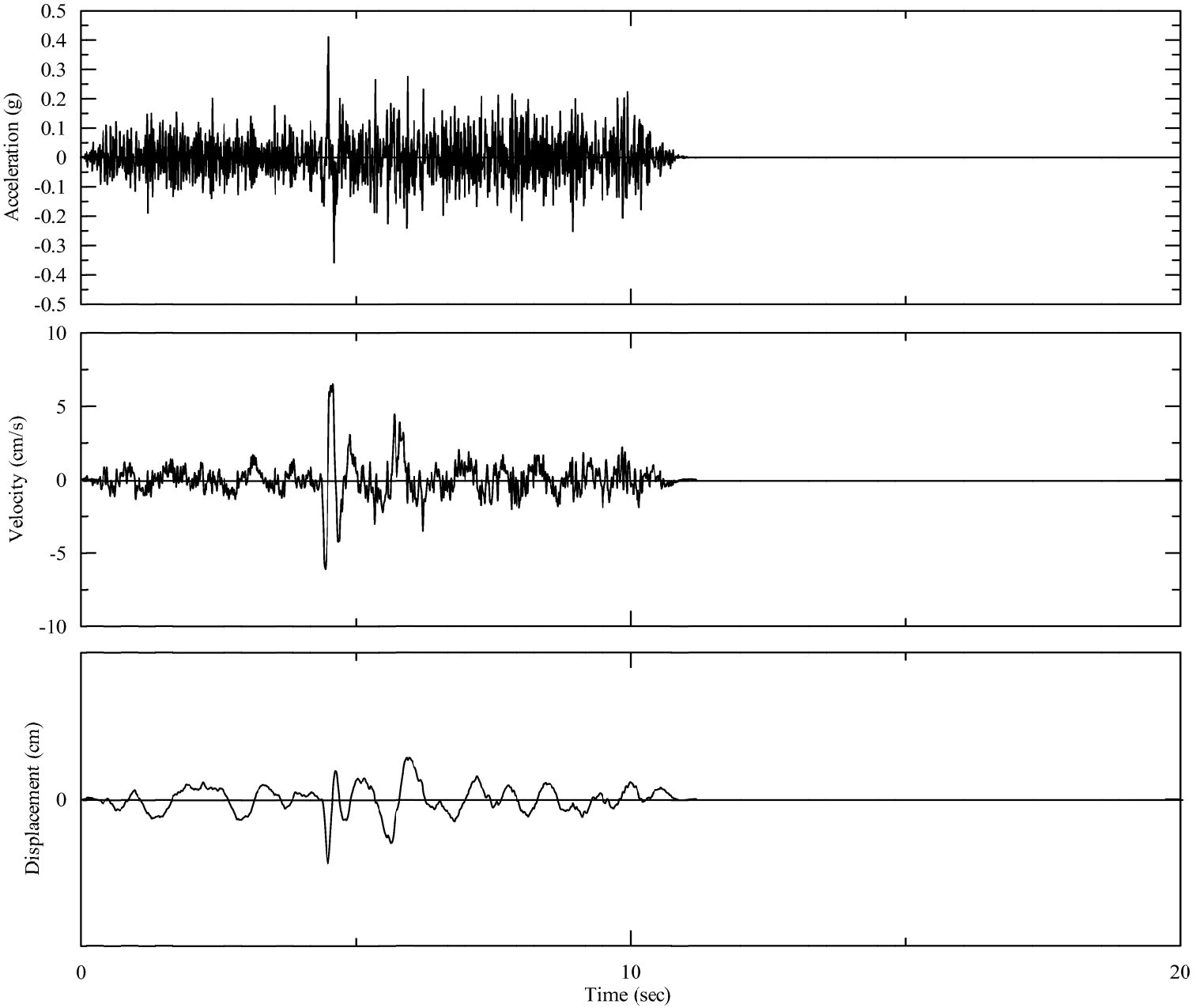

Acceleration, Velocity, and Displacement Time Histories N. Palm Springs, HCP045 Station, Horizontal Component	AMEC Geomatrix
Project No. 13452.003	Figure 17

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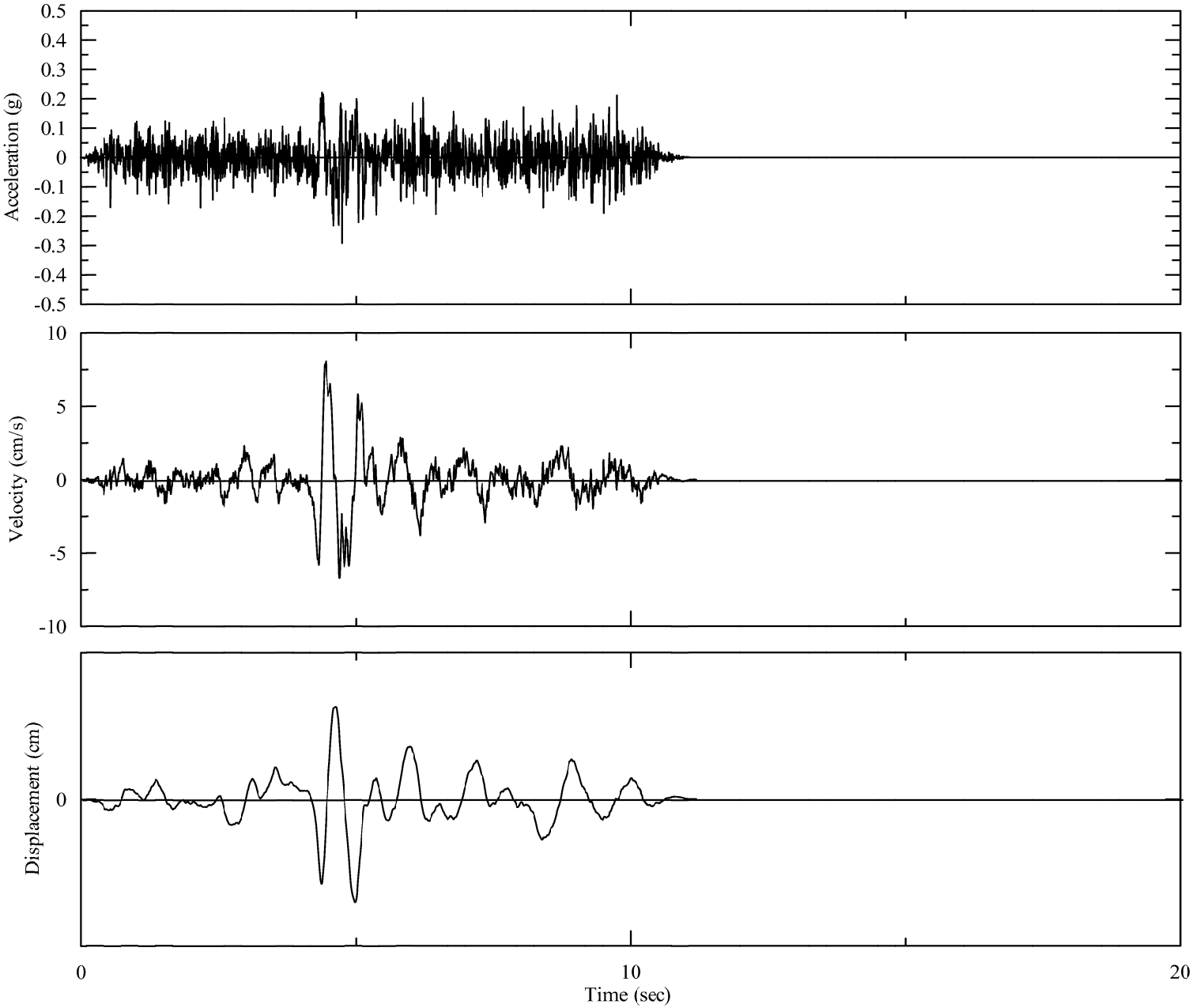

Acceleration, Velocity, and Displacement Time Histories N. Palm Springs, HCP135 Station, Horizontal Component	AMEC Geomatrix
Project No. 13452.003	Figure 18

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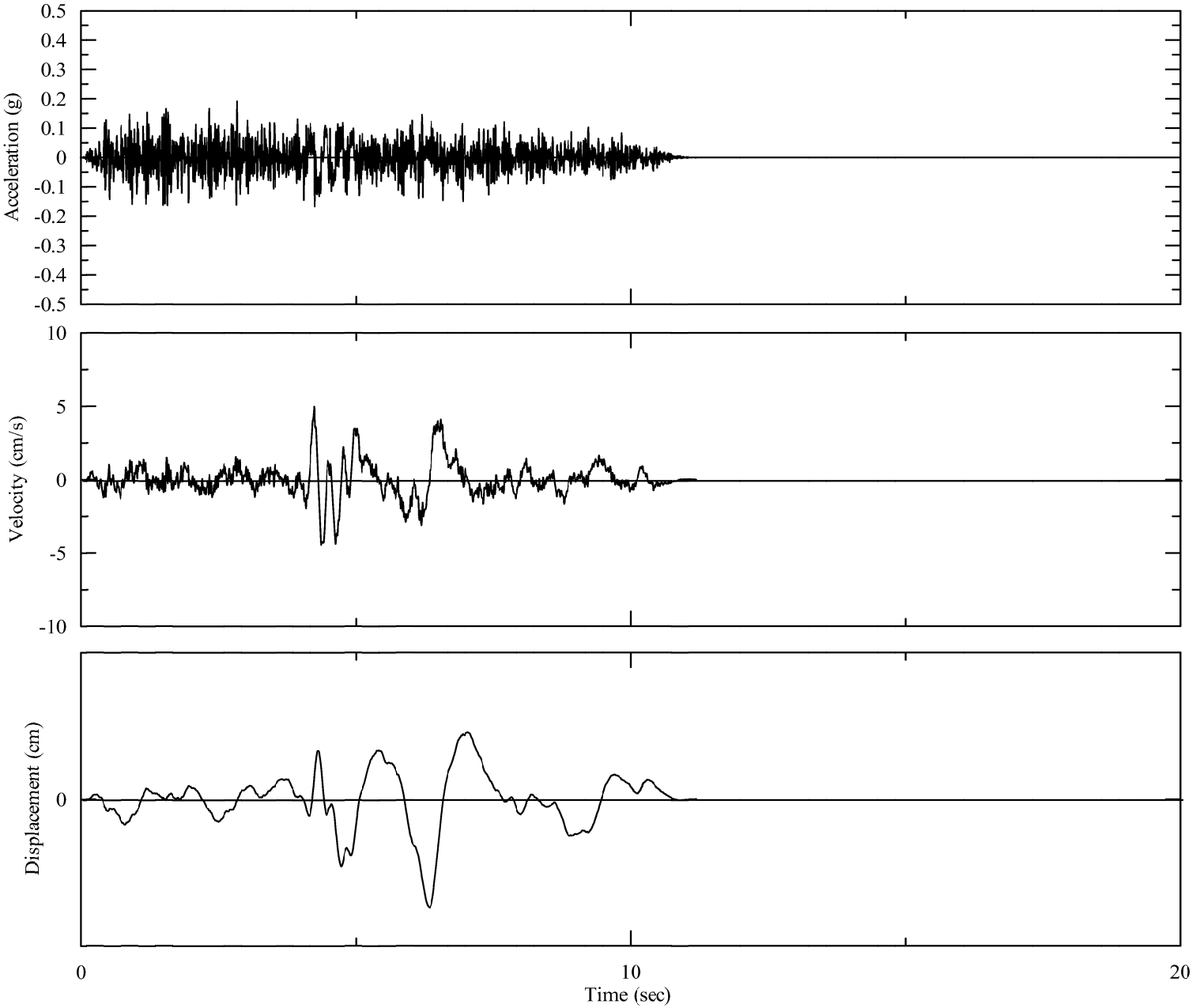

Acceleration, Velocity, and Displacement Time Histories N. Palm Springs, HCP-UP Station, Horizontal Component	AMEC Geomatrix
Project No. 13452.003	Figure 19

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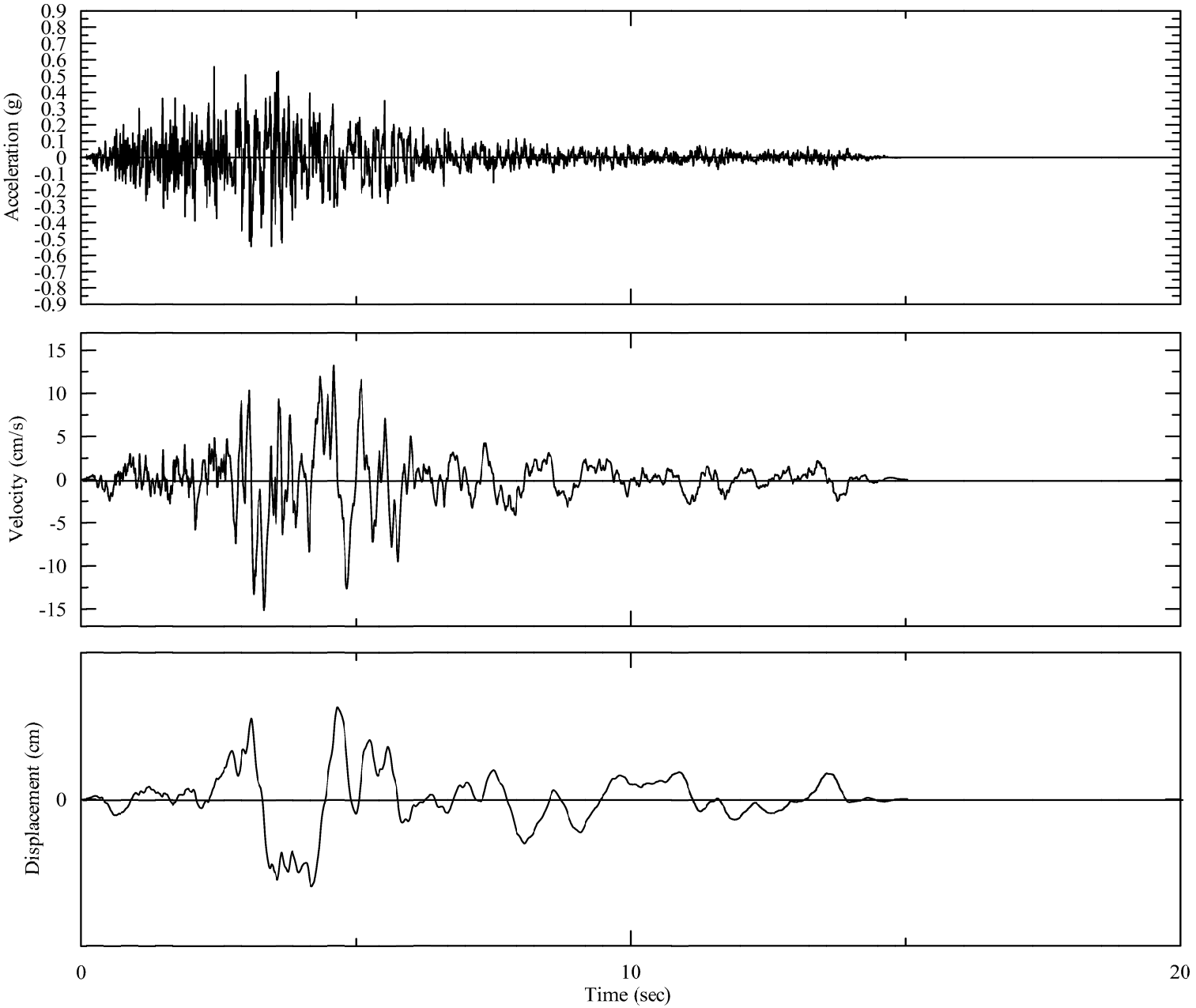

Acceleration, Velocity, and Displacement Time Histories Whittier Narrows, A-GRV060 Station, Horizontal Component	AMEC Geomatrix
Project No. 13452.003	Figure 20

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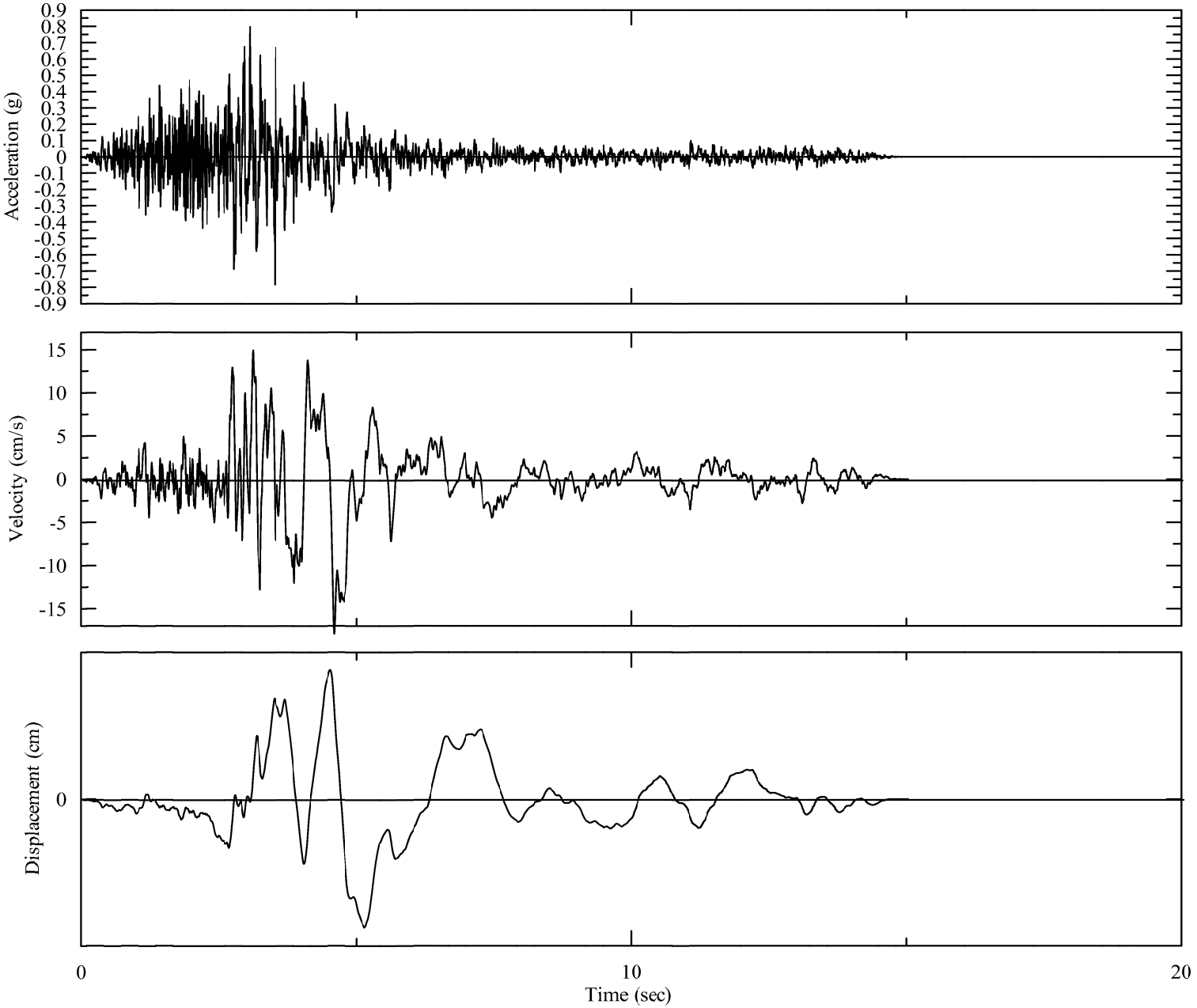

Acceleration, Velocity, and Displacement Time Histories Whittier Narrows, A-GRV330 Station, Horizontal Component	AMEC Geomatrix
Project No. 13452.003	Figure 21

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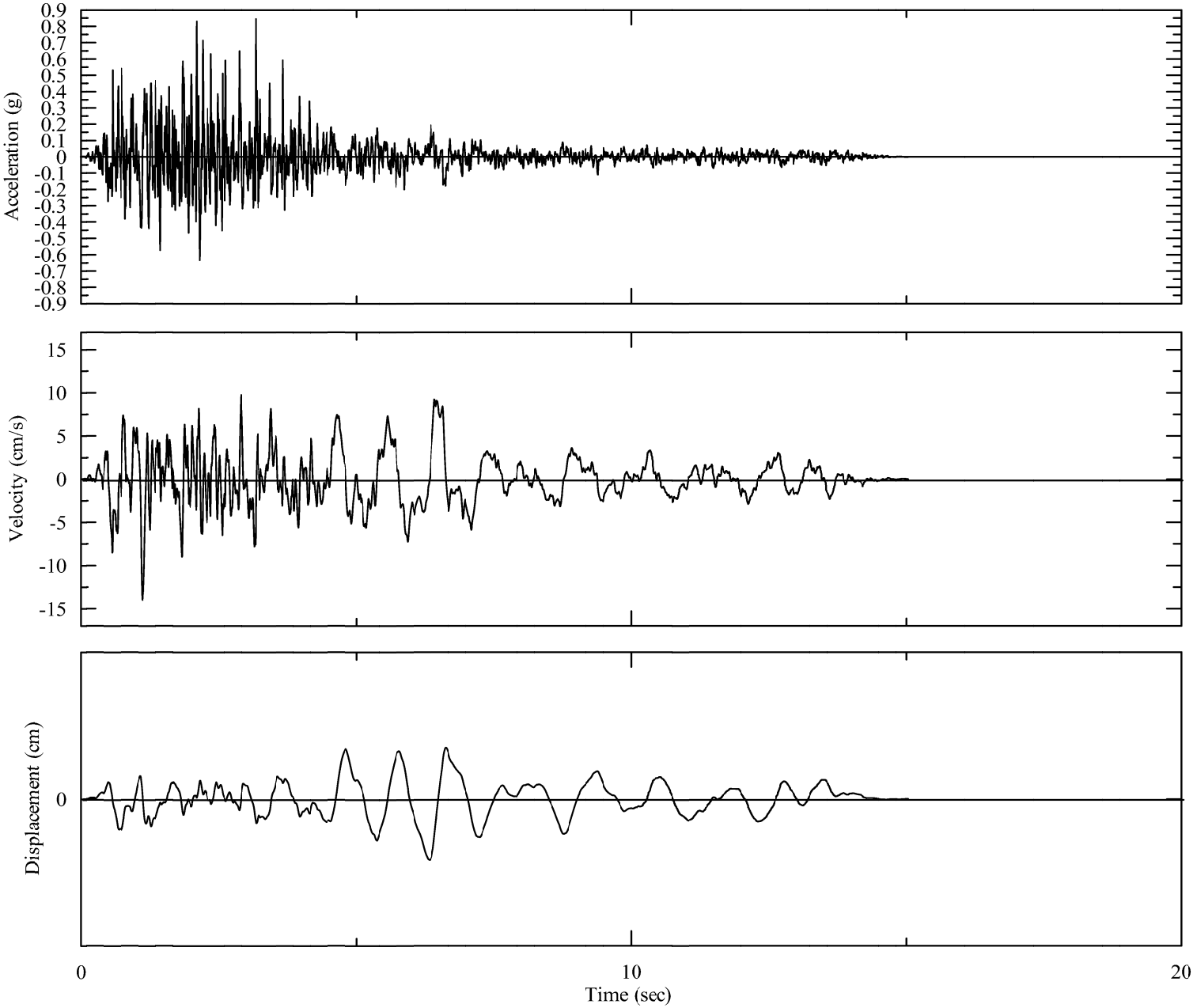

Acceleration, Velocity, and Displacement Time Histories Whittier Narrows, A-GRV-UP Station, Horizontal Component	AMEC Geomatrix
Project No. 13452.003	Figure 22

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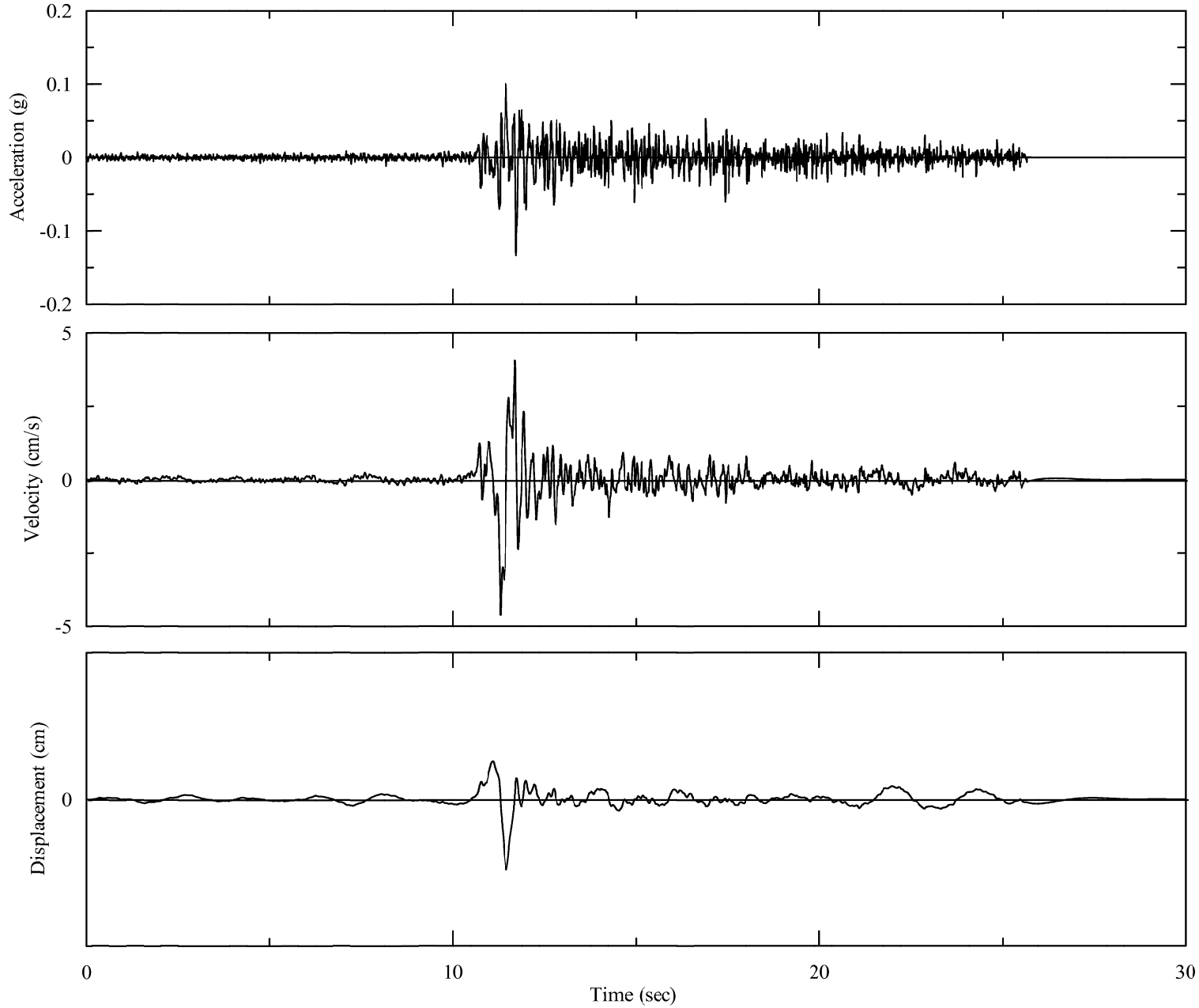

Acceleration, Velocity, and Displacement Time Histories Saguenay, 1125S08L Station, Horizontal Component	AMEC Geomatrix
Project No. 13452.003	Figure 23

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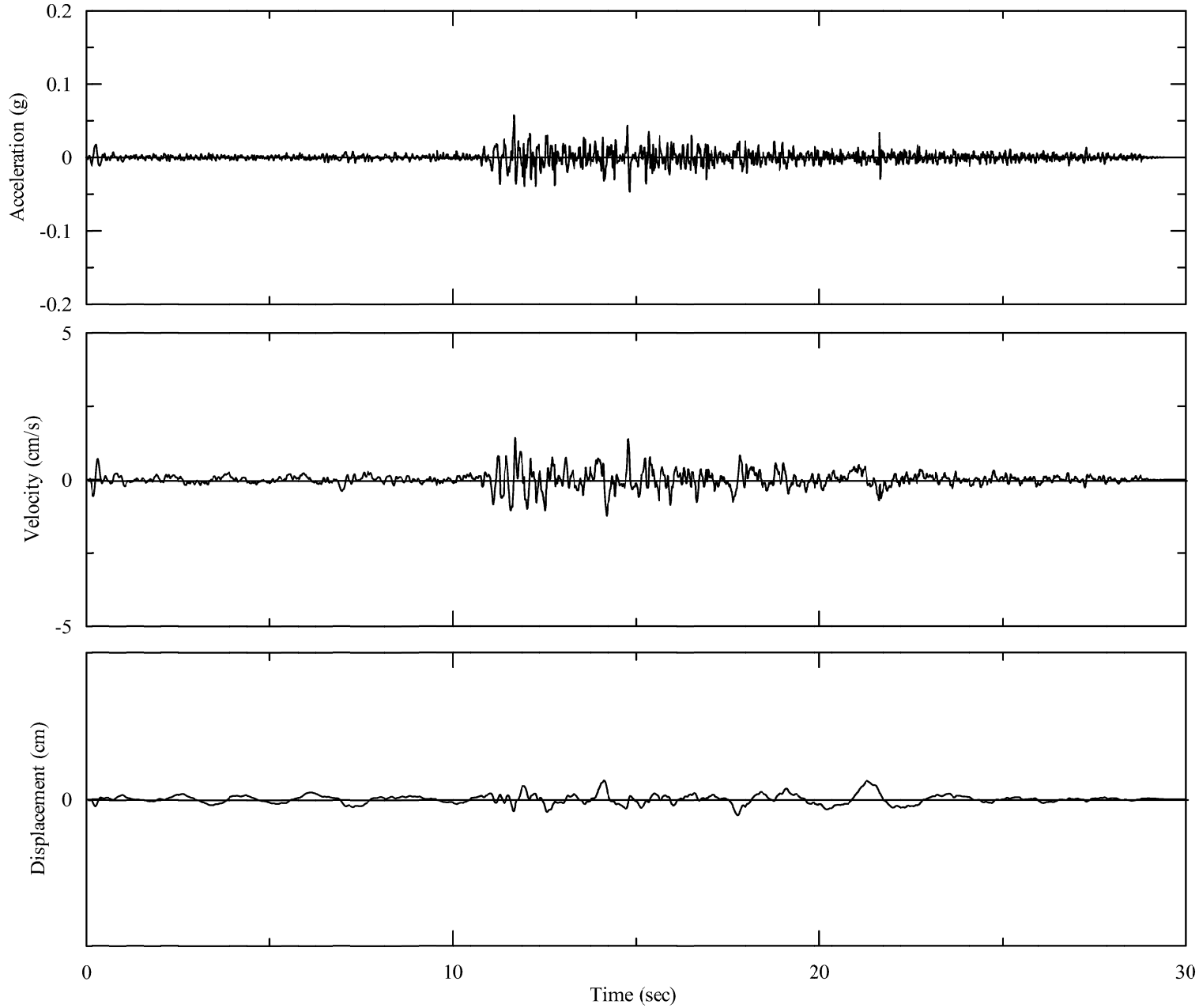

Acceleration, Velocity, and Displacement Time Histories Saguenay, 1125S08T Station, Horizontal Component		AMEC Geomatrix
Project No. 13452.003		Figure 24

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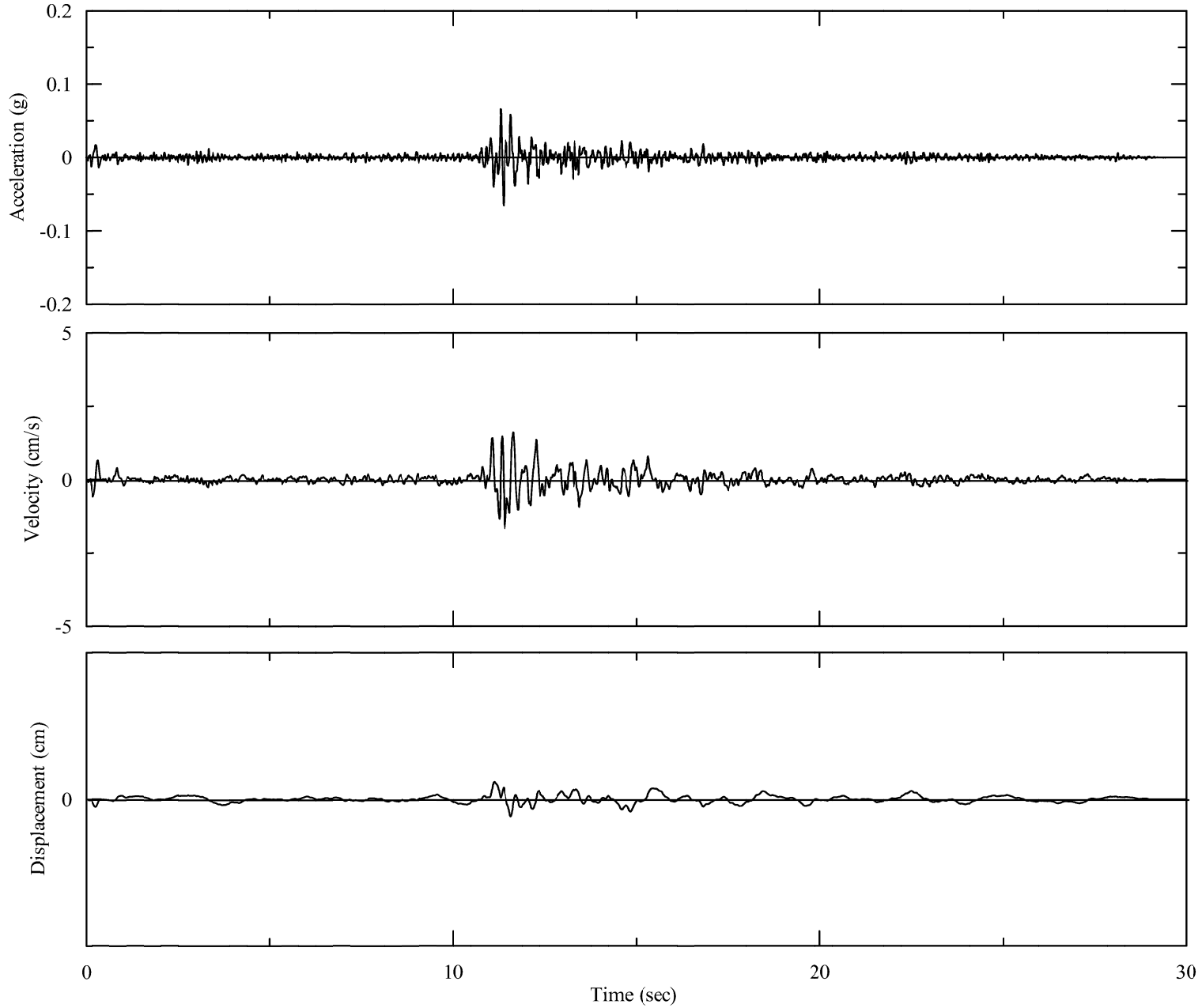

Acceleration, Velocity, and Displacement Time Histories Saguenay, 1125S08V Station, Horizontal Component	AMEC Geomatrix
Project No. 13452.003	Figure 25

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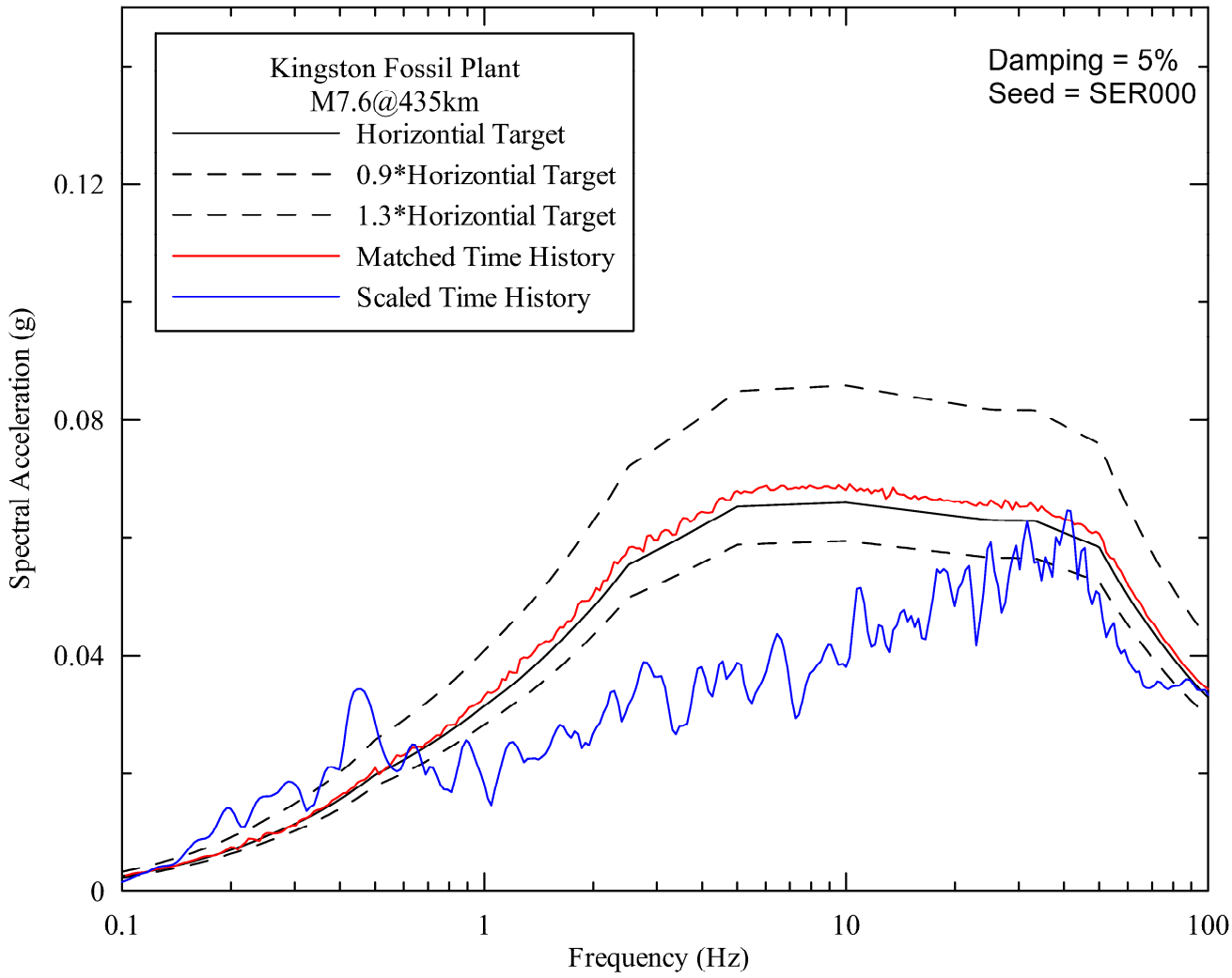


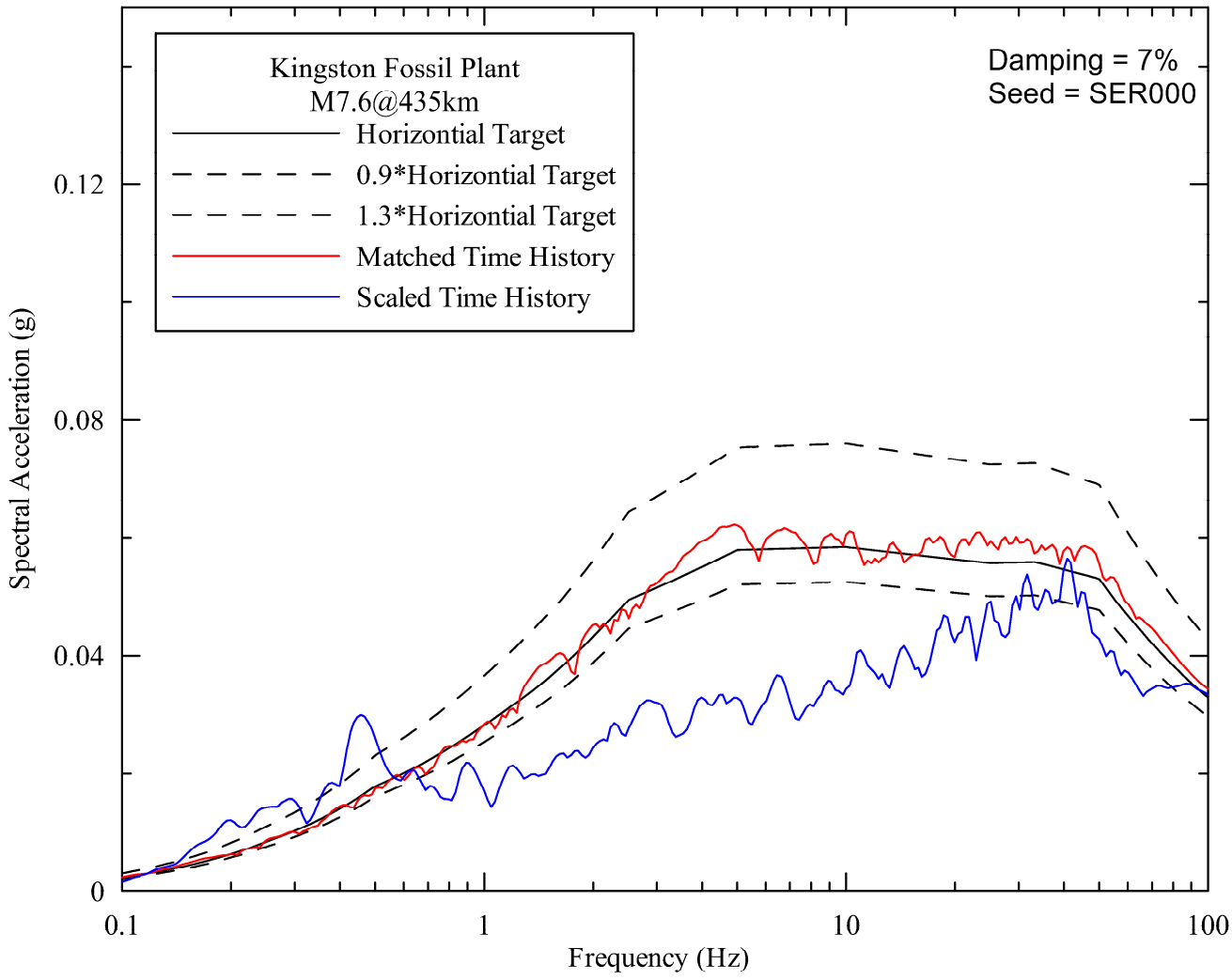
Horizontial Target and Matched Response Spectra (5% Damping)
For the M7.6, 435 km Scenario Earthquake

AMEC Geomatrix

Project No: 13452.003

Figure 26

I:\Project\13000\13452.003\12000 CALCS EVALS ANALYSIS\Kingston\Figures\Target_SER000_3_5%.grf



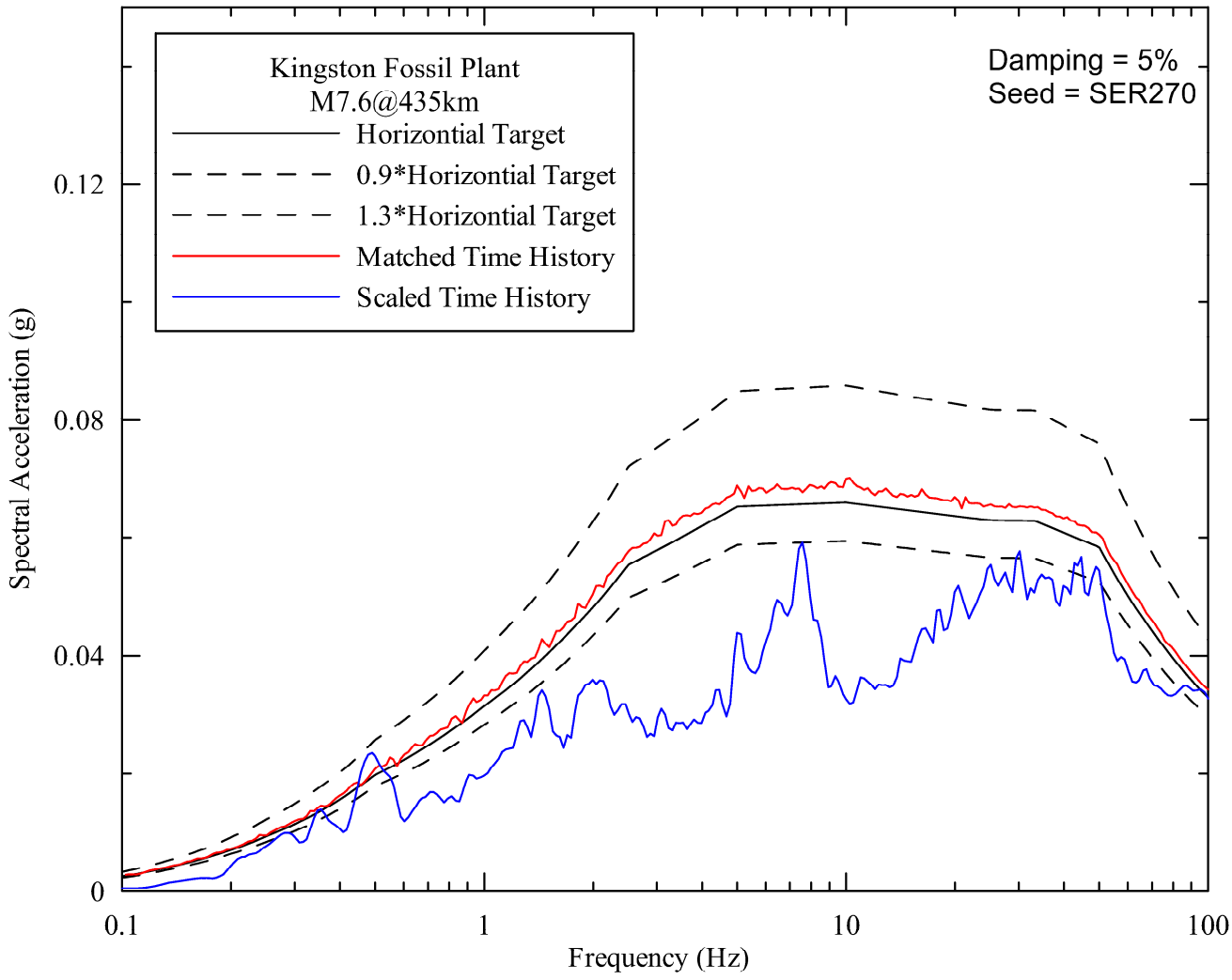
Horizontial Target and Matched Response Spectra (7% Damping)
For the M7.6, 435 km Scenario Earthquake

AMEC Geomatrix

Project No: 13452.003

Figure 27

I:\Project\13000\13452.003\12000 CALCS EVALS ANALYSIS\Kingston\Figures\Target_SER000_3_7%.grf



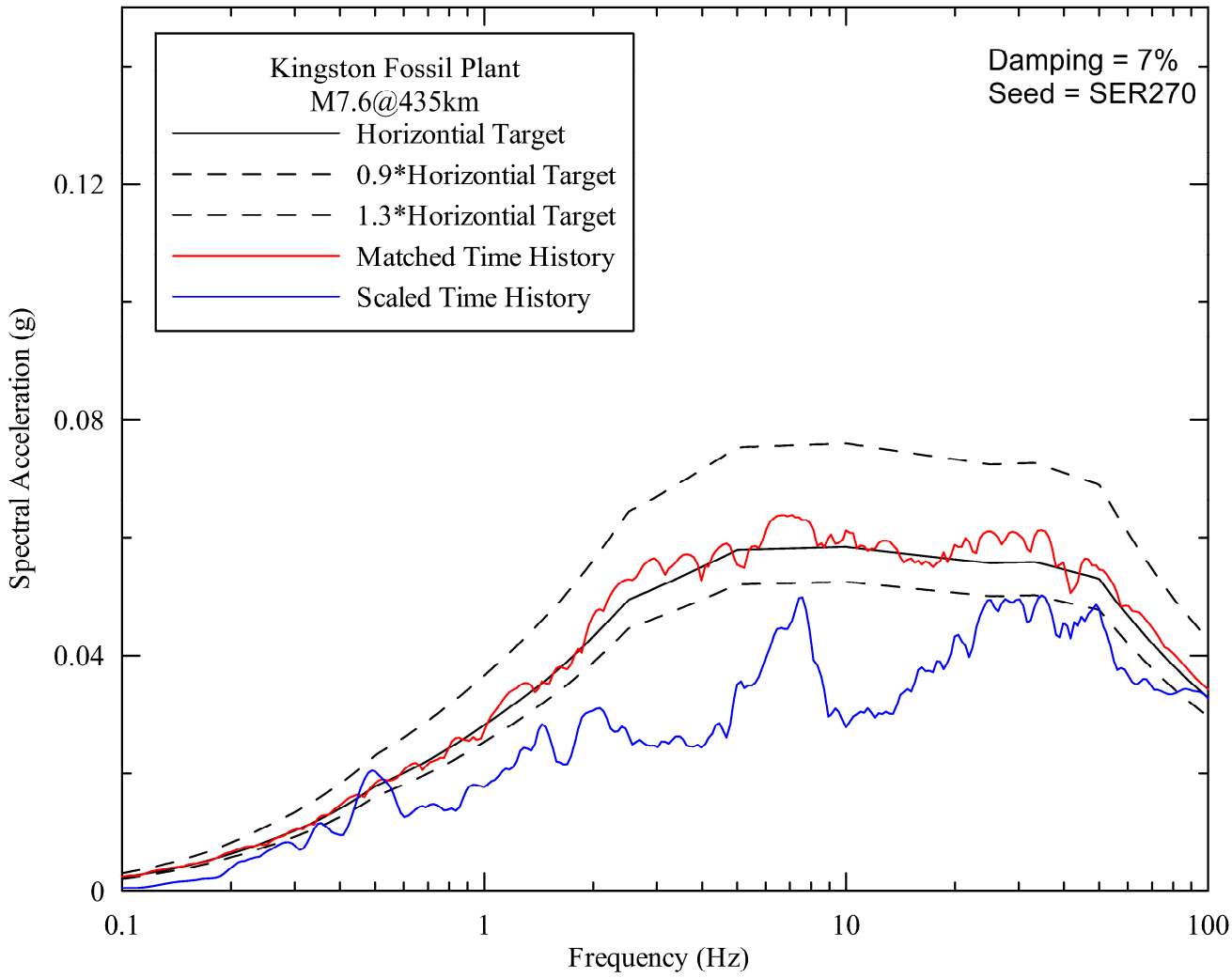
Horizontial Target and Matched Response Spectra (5% Damping)
For the M7.6, 435 km Scenario Earthquake

AMEC Geomatrix

Project No: 13452.003

Figure 28

I:\Project\13000\13452.003\12000 CALCS EVALS ANALYSIS\Kingston\Figures\Target_SER270_3_5%.grf



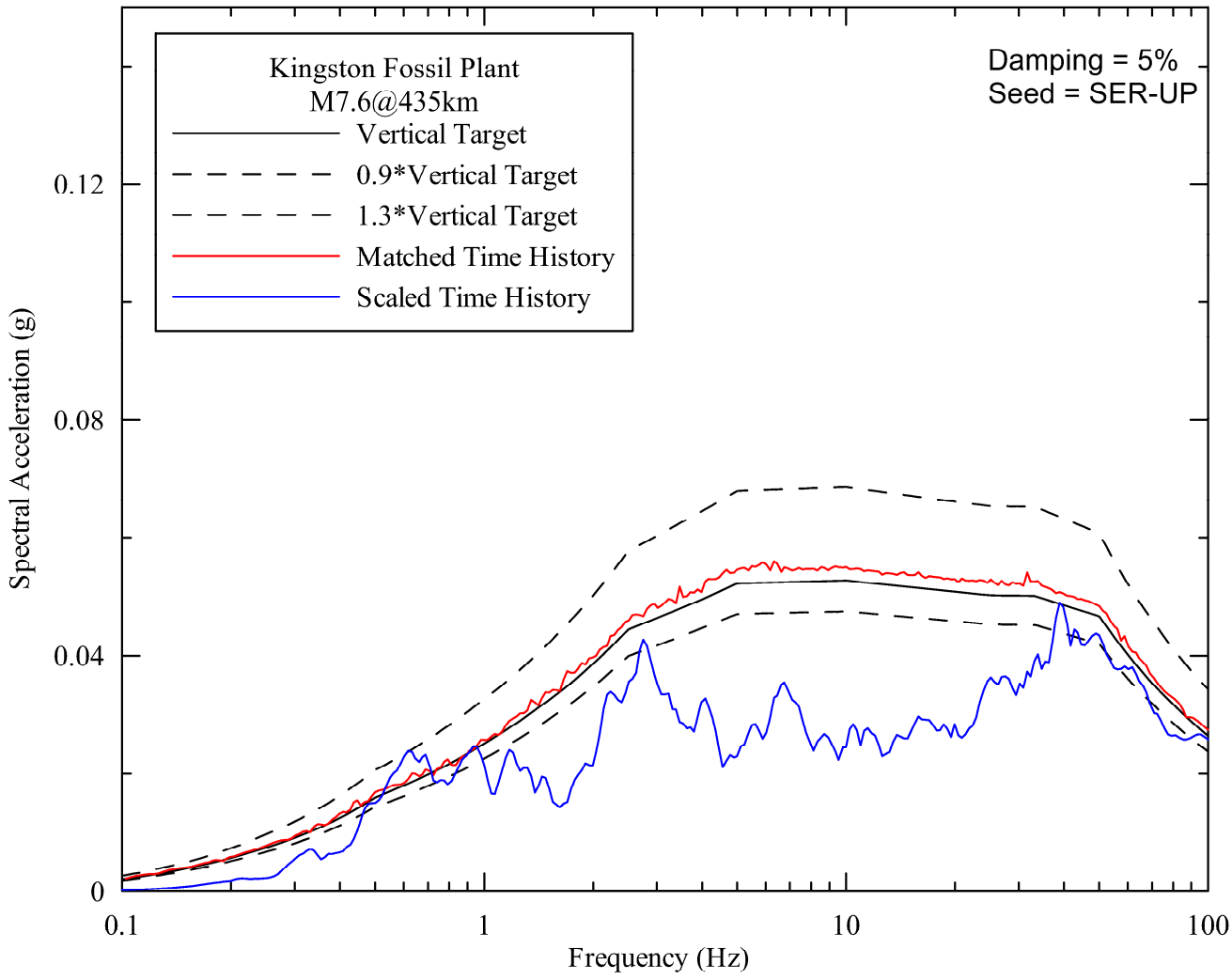
Horizontial Target and Matched Response Spectra (7% Damping)
For the M7.6, 435 km Scenario Earthquake

AMEC Geomatrix

Project No: 13452.003

Figure 29

I:\Project\13000\13452.003\12000 CALCS EVALS ANALYSIS\Kingston\Figures\Target_SER270_3_7%.grf



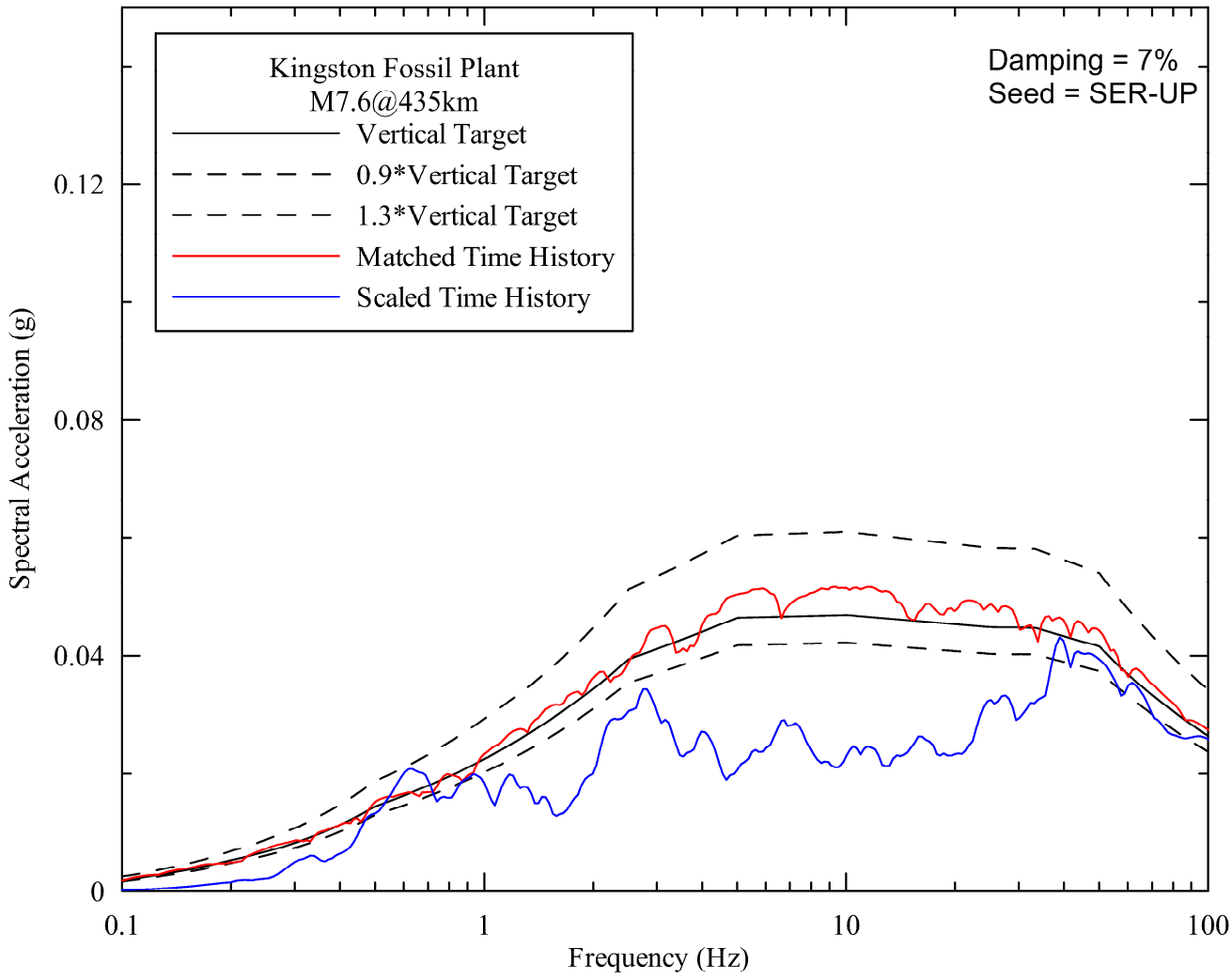
Vertical Target and Matched Response Spectra (5% Damping)
For the M7.6, 435 km Scenario Earthquake

AMEC Geomatrix

Project No: 13452.003

Figure 30

I:\Project\13000\13452.003\12000 CALCS EVALS ANALYSIS\Kingston\Figures\Target_SER-UP_3_5%.grf



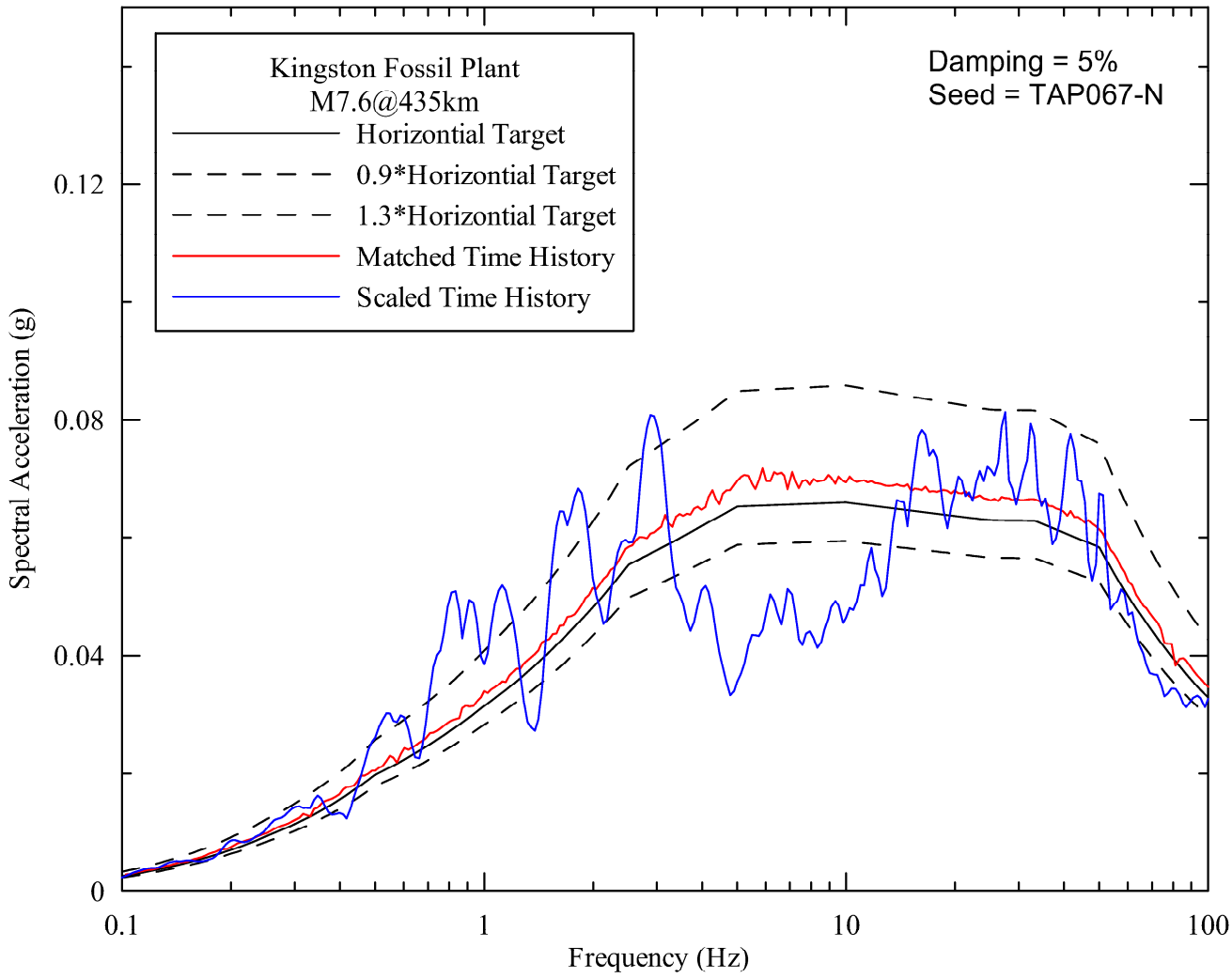
Vertical Target and Matched Response Spectra (7% Damping)
For the M7.6, 435 km Scenario Earthquake

AMEC Geomatrix

Project No: 13452.003

Figure 31

I:\Project\13000\13452.003\12000 CALCS EVALS ANALYSIS\Kingston\Figures\Target_SER-UP_3_7%.grf



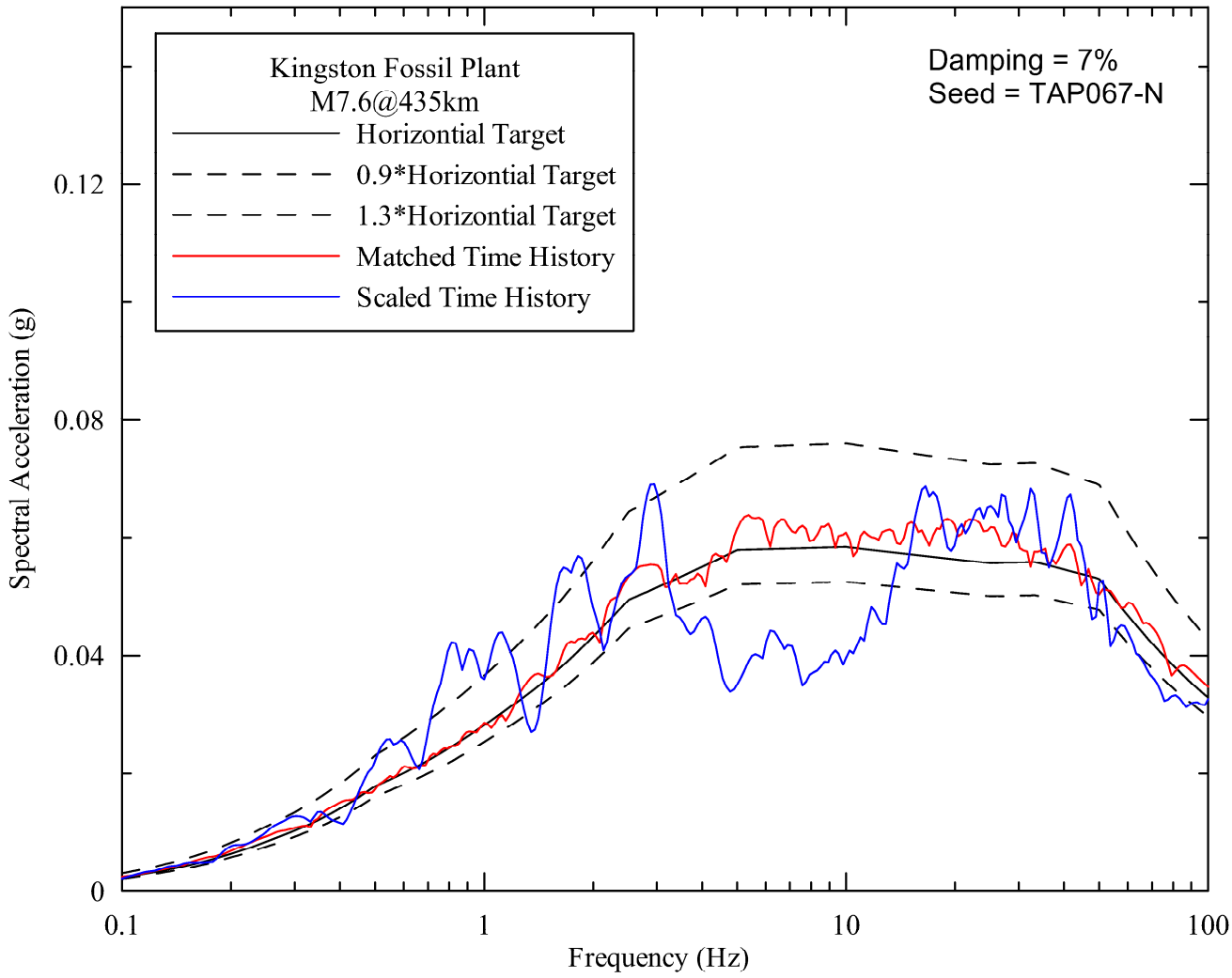
Horizontial Target and Matched Response Spectra (5% Damping)
For the M7.6, 435 km Scenario Earthquake

AMEC Geomatrix

Project No: 13452.003

Figure 32

I:\Project\13000\13452.003\12000 CALCS EVALS ANALYSIS\Kingston\Figures\Target_TAP067-N_5%.grf



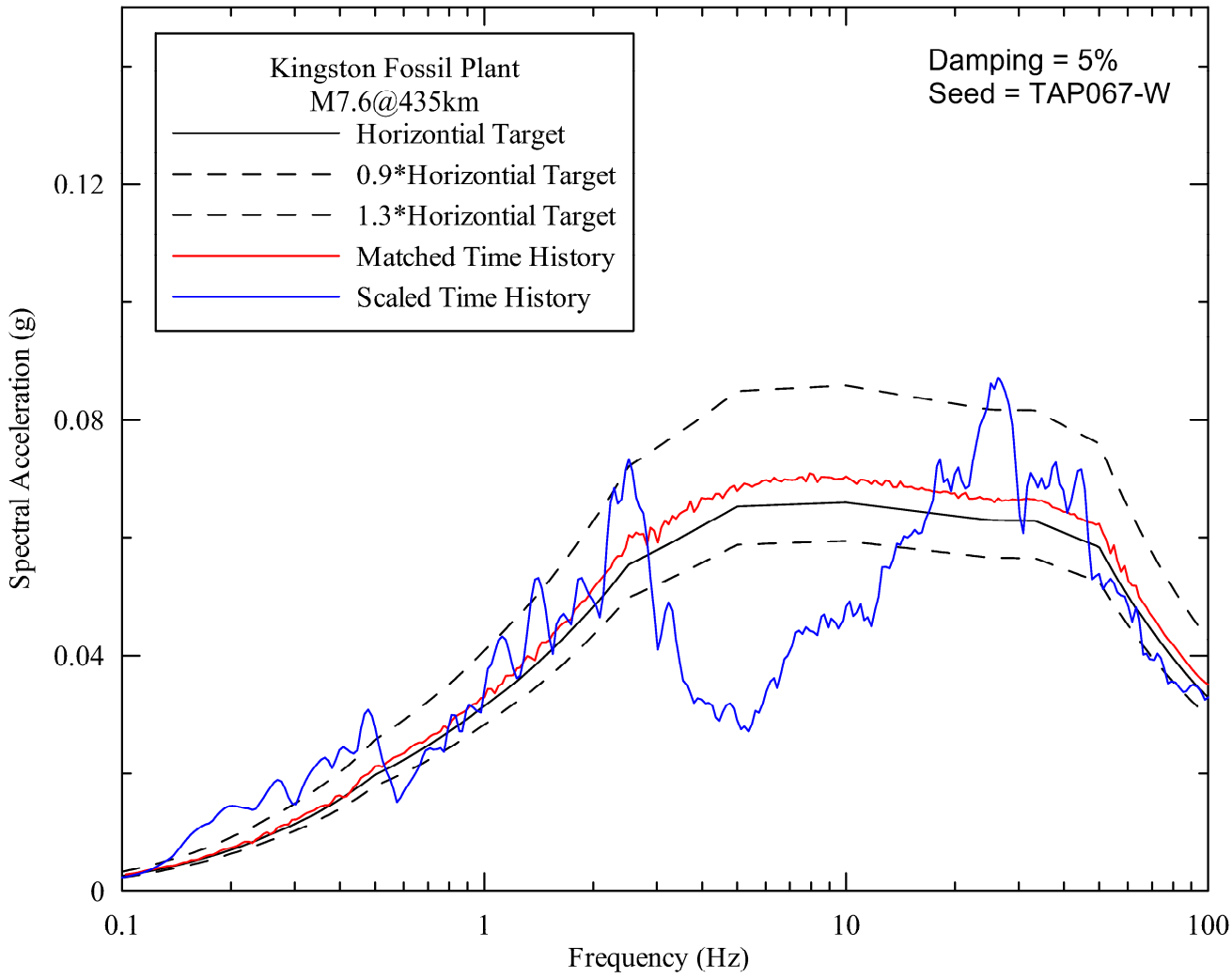
Horizontial Target and Matched Response Spectra (7% Damping)
For the M7.6, 435 km Scenario Earthquake

AMEC Geomatrix

Project No: 13452.003

Figure 33

I:\Project\13000\13452.003\12000 CALCS EVALS ANALYSIS\Kingston\Figures\Target_TAP067-N_7%.grf



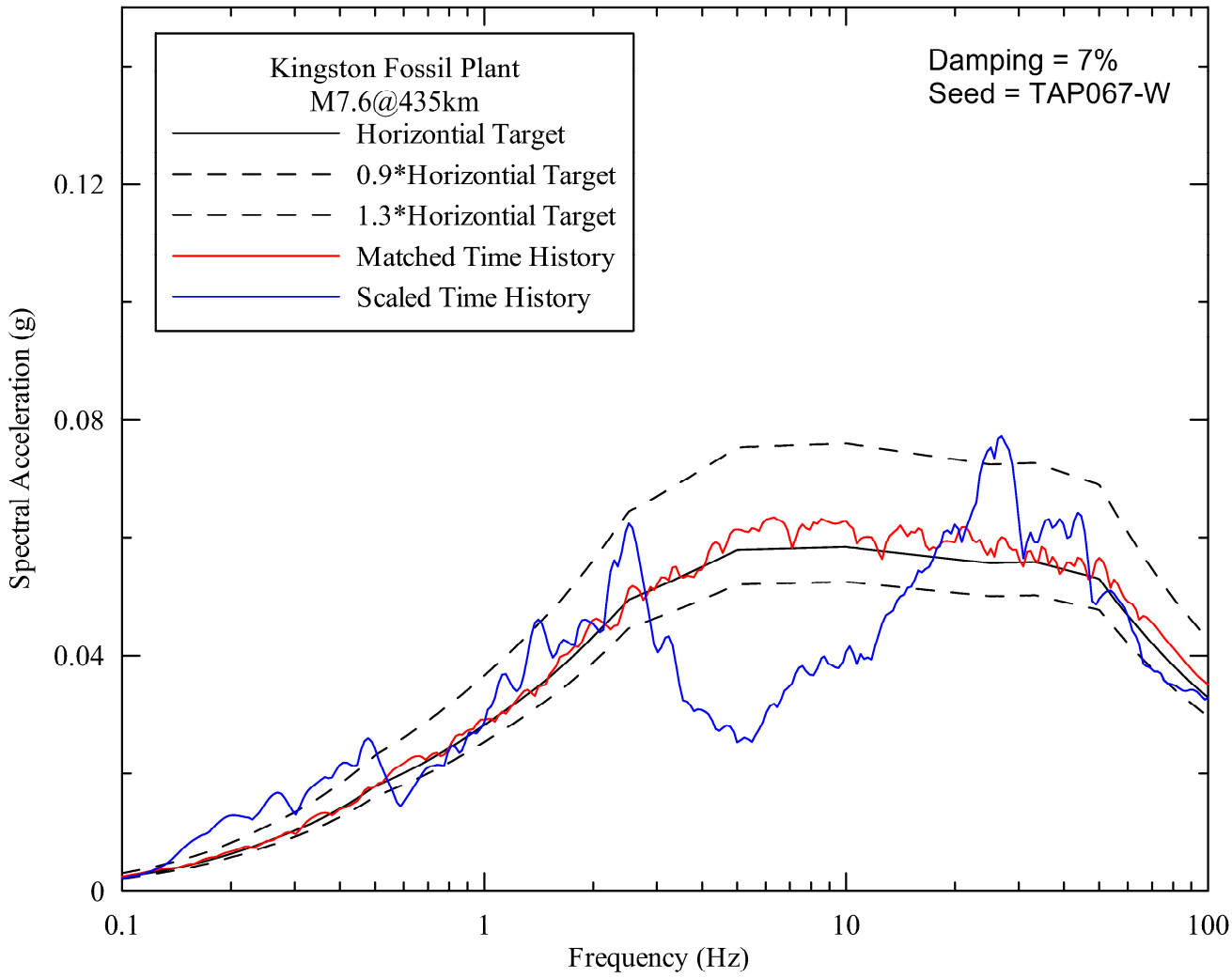
Horizontial Target and Matched Response Spectra (5% Damping)
For the M7.6, 435 km Scenario Earthquake

AMEC Geomatrix

Project No: 13452.003

Figure 34

I:\Project\13000\13452.003\12000 CALCS EVALS ANALYSIS\Kingston\Figures\Target_TAP067-W_5%.grf



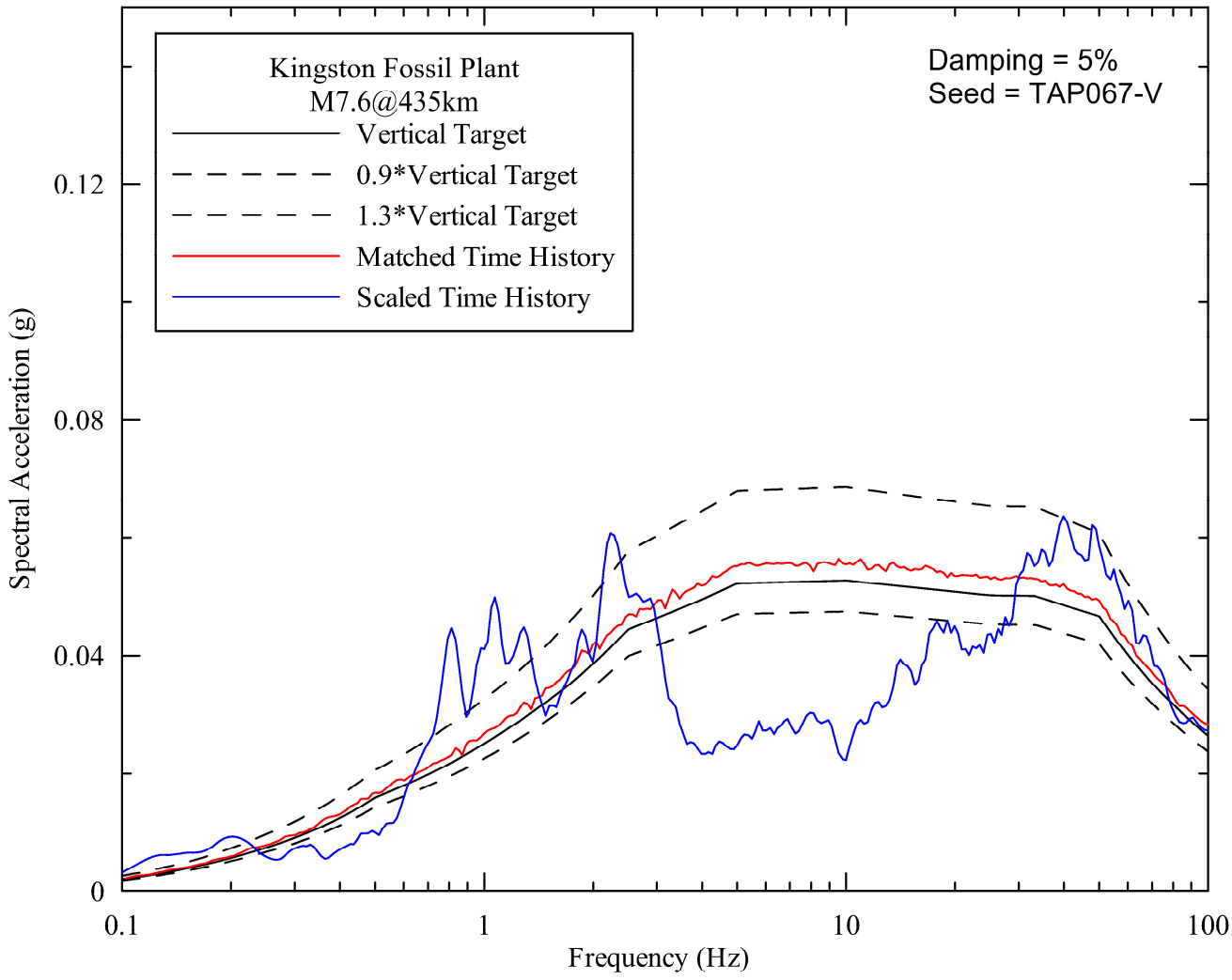
Horizontial Target and Matched Response Spectra (7% Damping)
For the M7.6, 435 km Scenario Earthquake

AMEC Geomatrix

Project No: 13452.003

Figure 35

I:\Project\13000\13452.003\12000 CALCS EVALS ANALYSIS\Kingston\Figures\Target_TAP067-W_7%.grf



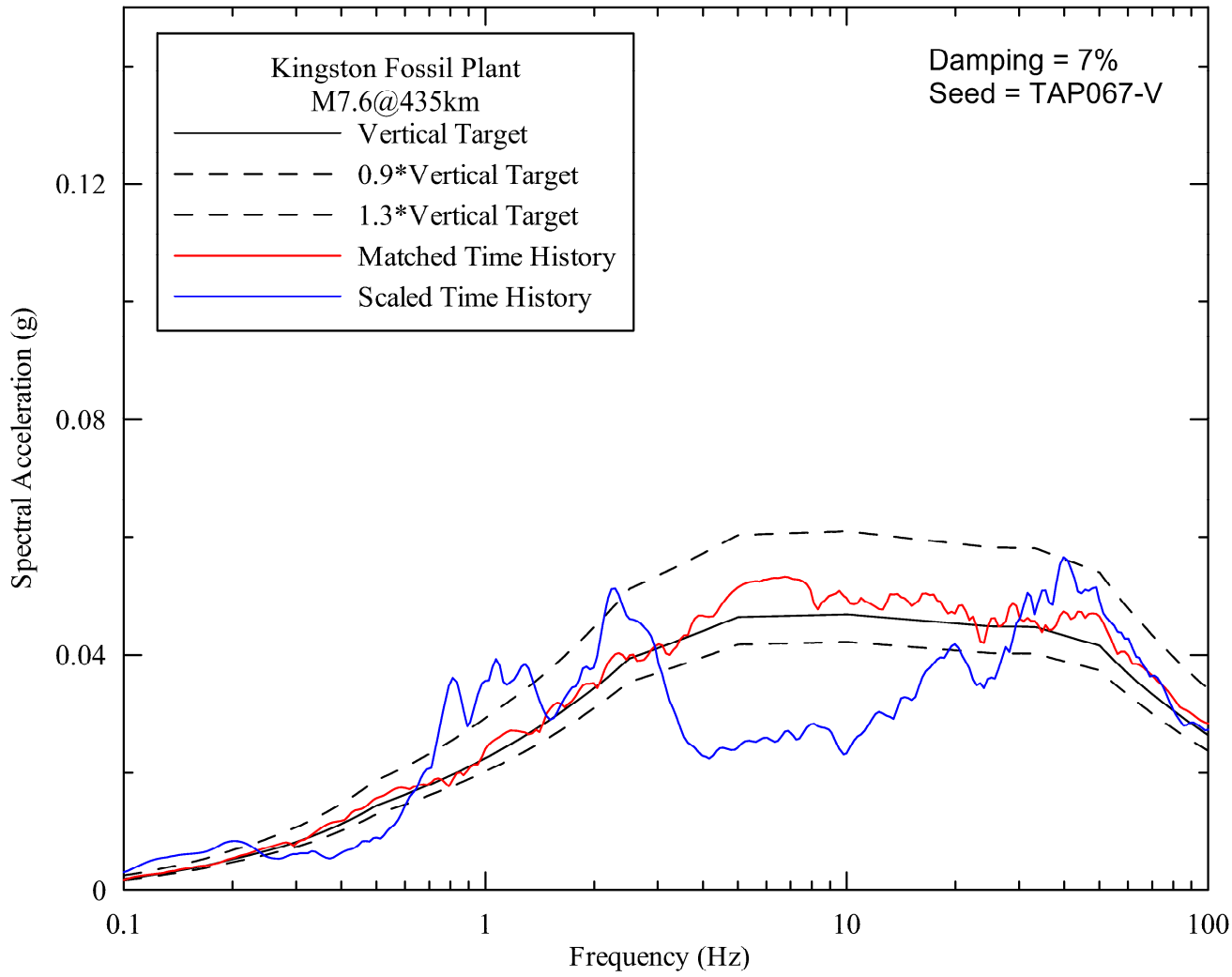
Vertical Target and Matched Response Spectra (5% Damping)
For the M7.6, 435 km Scenario Earthquake

AMEC Geomatrix

Project No: 13452.003

Figure 36

I:\Project\13000\13452.003\12000 CALCS EVALS ANALYSIS\Kingston\Figures\Target_TAP067-V_5%.grf



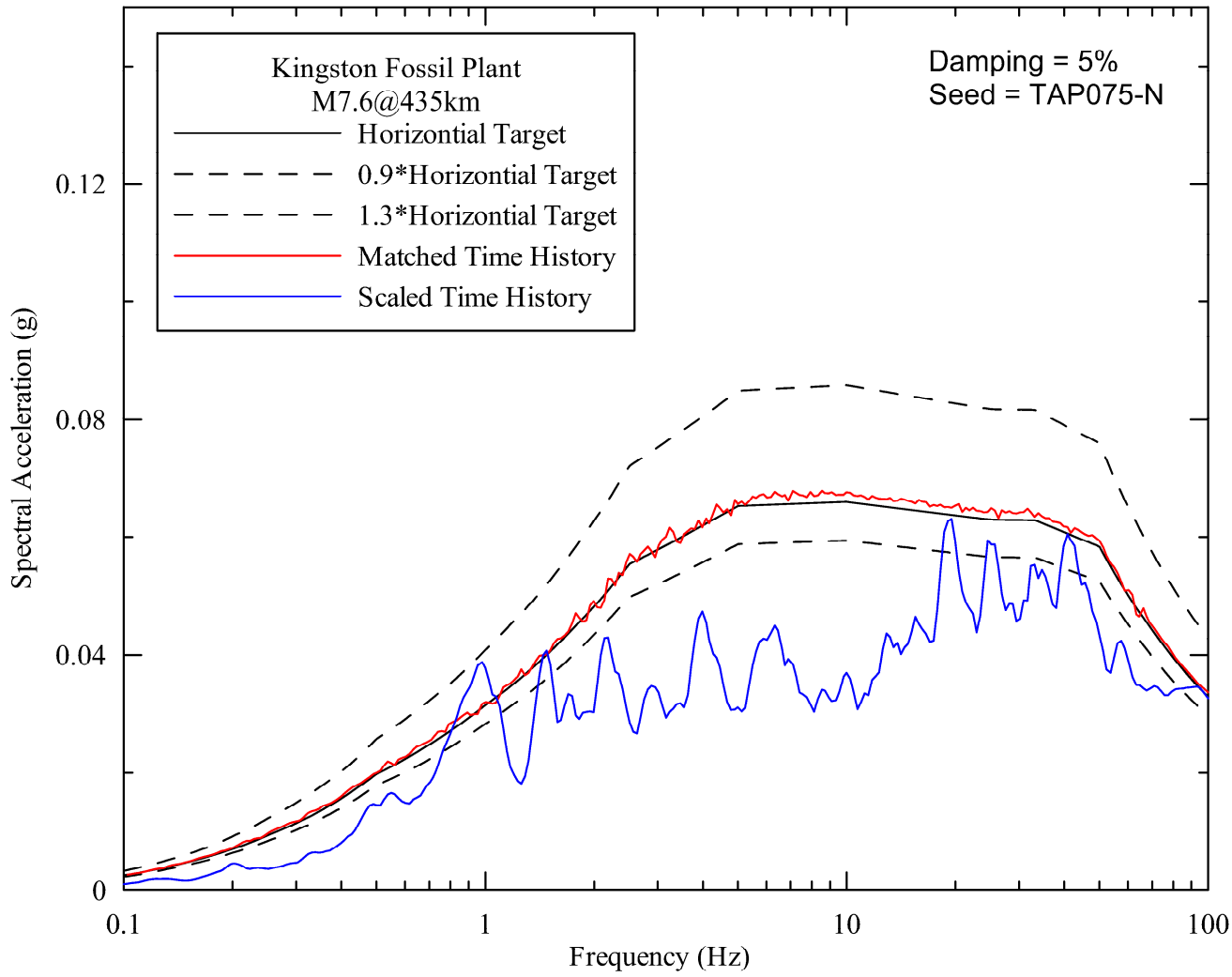
Vertical Target and Matched Response Spectra (7% Damping)
For the M7.6, 435 km Scenario Earthquake

AMEC Geomatrix

Project No: 13452.003

Figure 37

I:\Project\13000\13452.003\12000 CALCS EVALS ANALYSIS\Kingston\Figures\Target_TAP067-V_7%.grf



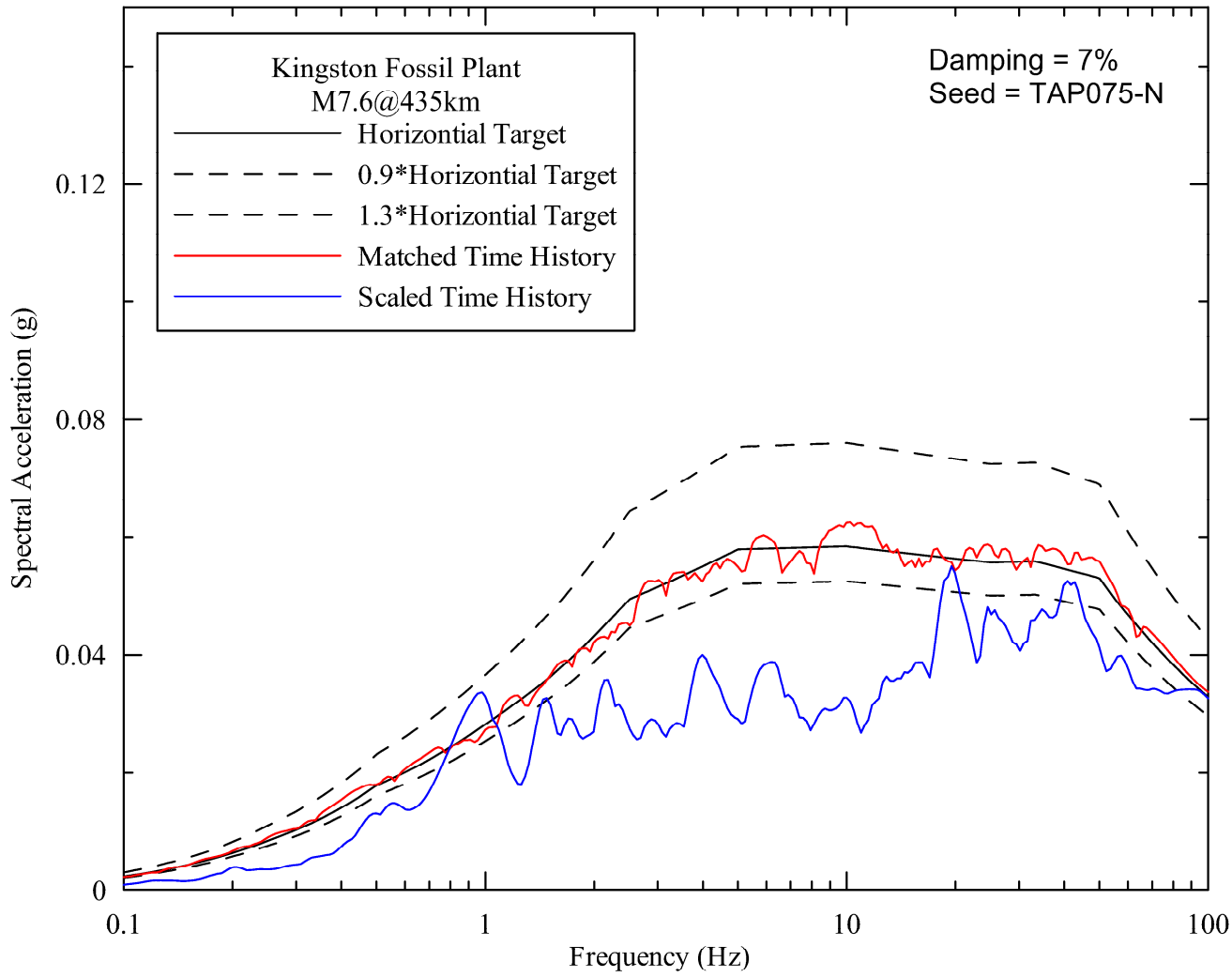
Horizontial Target and Matched Response Spectra (5% Damping)
For the M7.6, 435 km Scenario Earthquake

AMEC Geomatrix

Project No: 13452.003

Figure 38

I:\Project\13000\13452.003\12000 CALCS EVALS ANALYSIS\Kingston\Figures\Target_TAP075-N_5%.grf



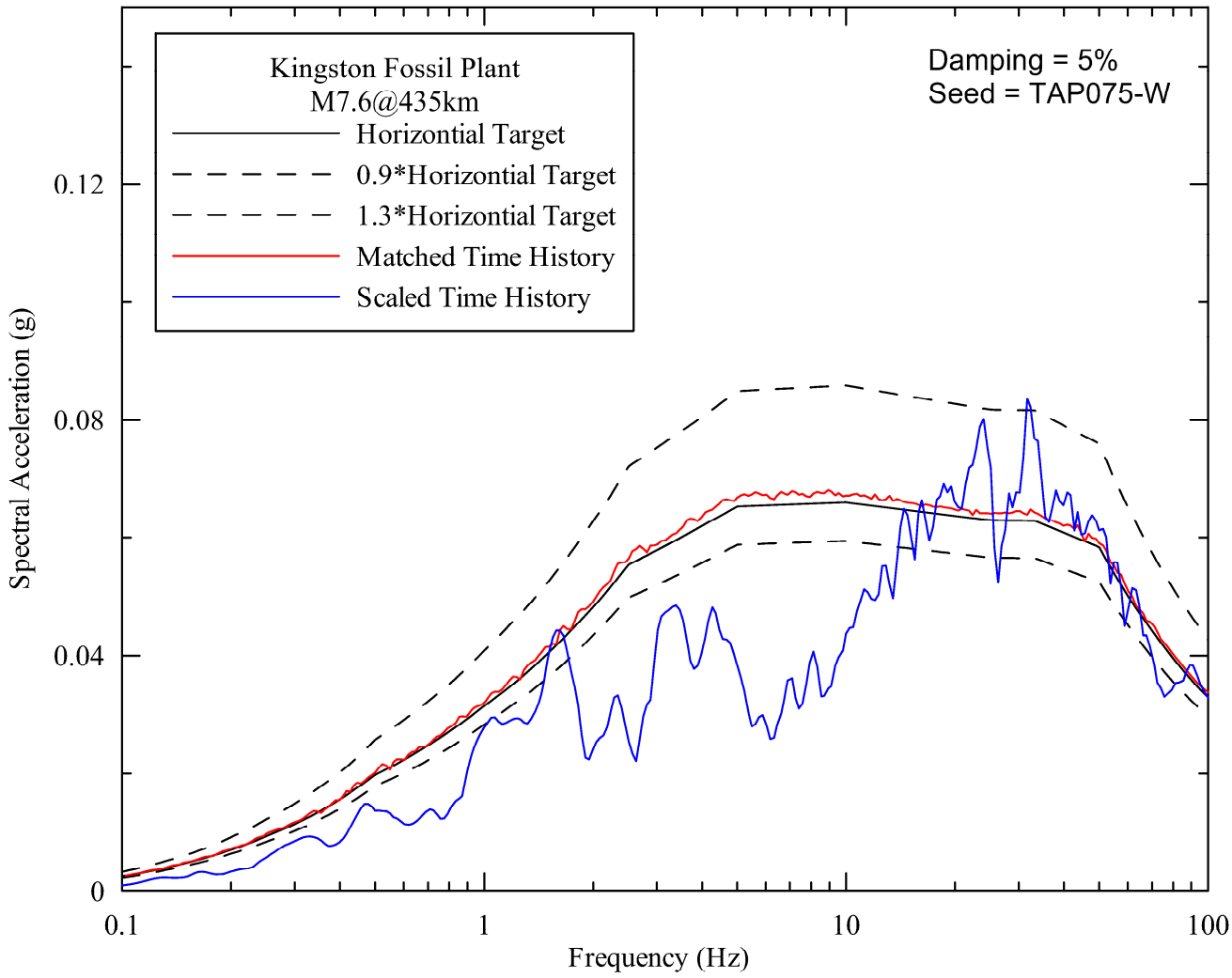
Horizontial Target and Matched Response Spectra (7% Damping)
For the M7.6, 435 km Scenario Earthquake

AMEC Geomatrix

Project No: 13452.003

Figure 39

I:\Project\13000\13452.003\12000 CALCS EVALS ANALYSIS\Kingston\Figures\Target_TAP075-N_7%.grf



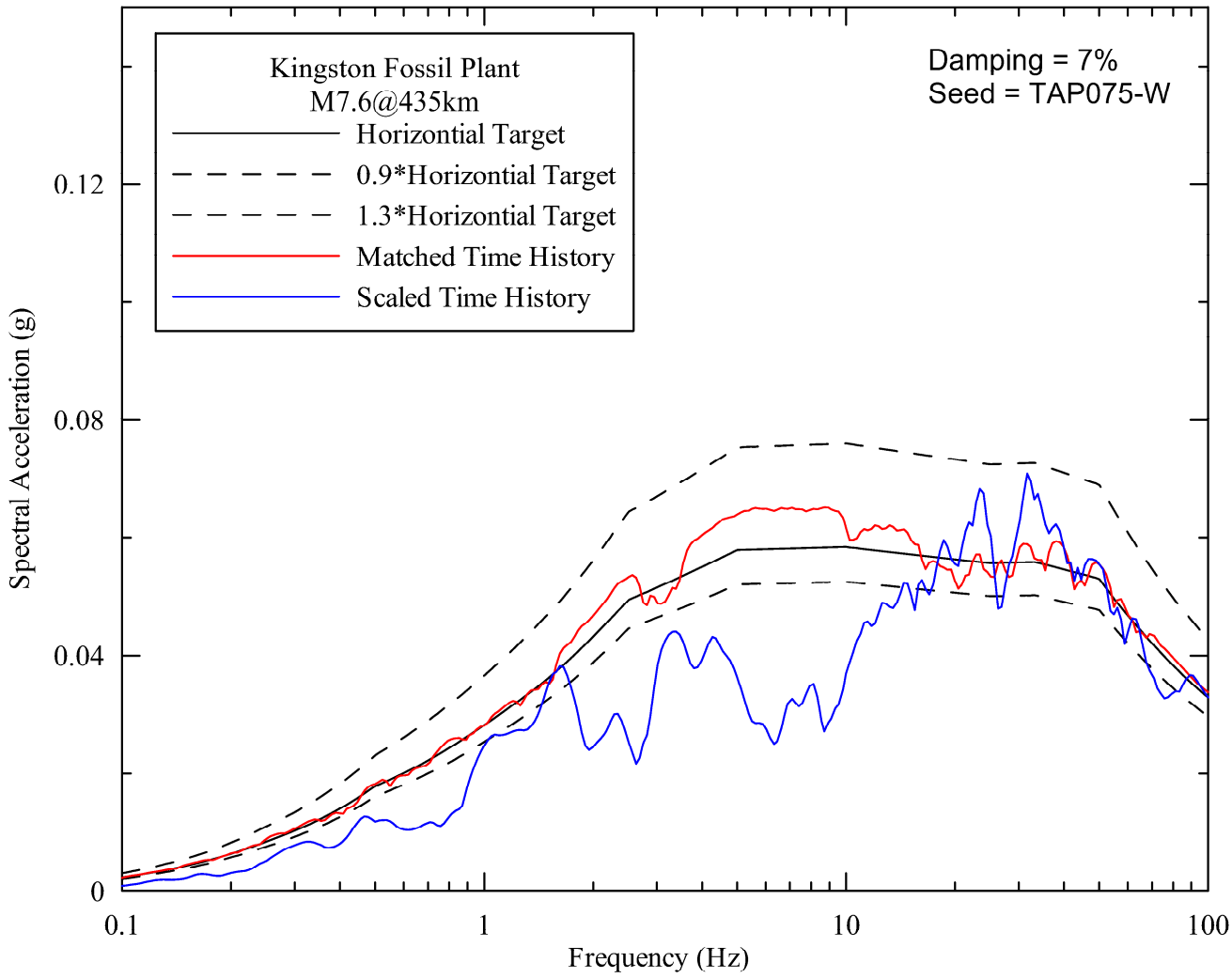
Horizontial Target and Matched Response Spectra (5% Damping)
For the M7.6, 435 km Scenario Earthquake

AMEC Geomatrix

Project No: 13452.003

Figure 40

I:\Project\13000\13452.003\12000 CALCS EVALS ANALYSIS\Kingston\Figures\Target_TAP075-W_5%.grf



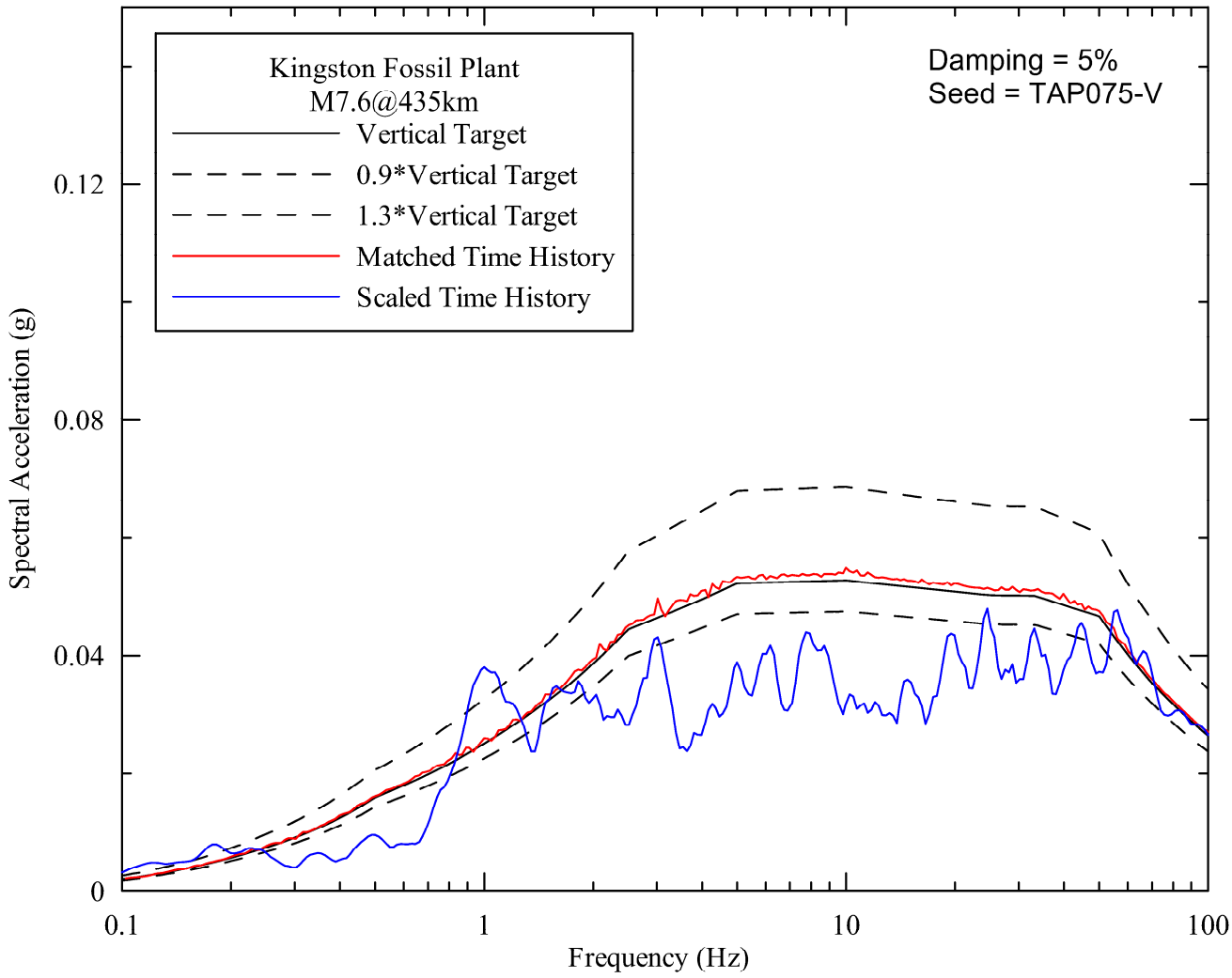
Horizontial Target and Matched Response Spectra (7% Damping)
For the M7.6, 435 km Scenario Earthquake

AMEC Geomatrix

Project No: 13452.003

Figure 41

I:\Project\13000\13452.003\12000 CALCS EVALS ANALYSIS\Kingston\Figures\Target_TAP075-W_7%.grf



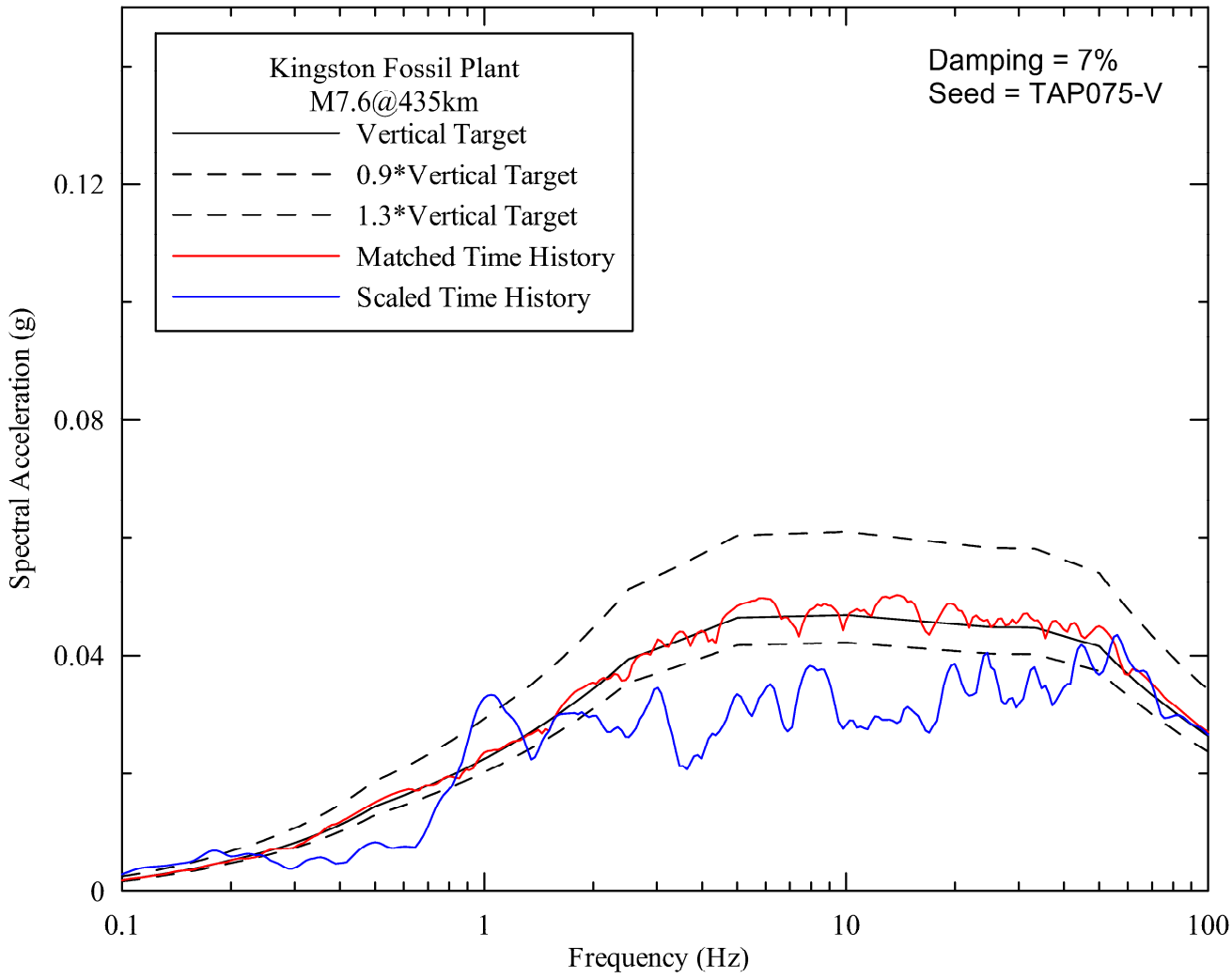
Vertical Target and Matched Response Spectra (5% Damping)
For the M7.6, 435 km Scenario Earthquake

AMEC Geomatrix

Project No: 13452.003

Figure 42

I:\Project\13000\13452.003\12000 CALCS EVALS ANALYSIS\Kingston\Figures\Target_TAP075-V_5%.grf



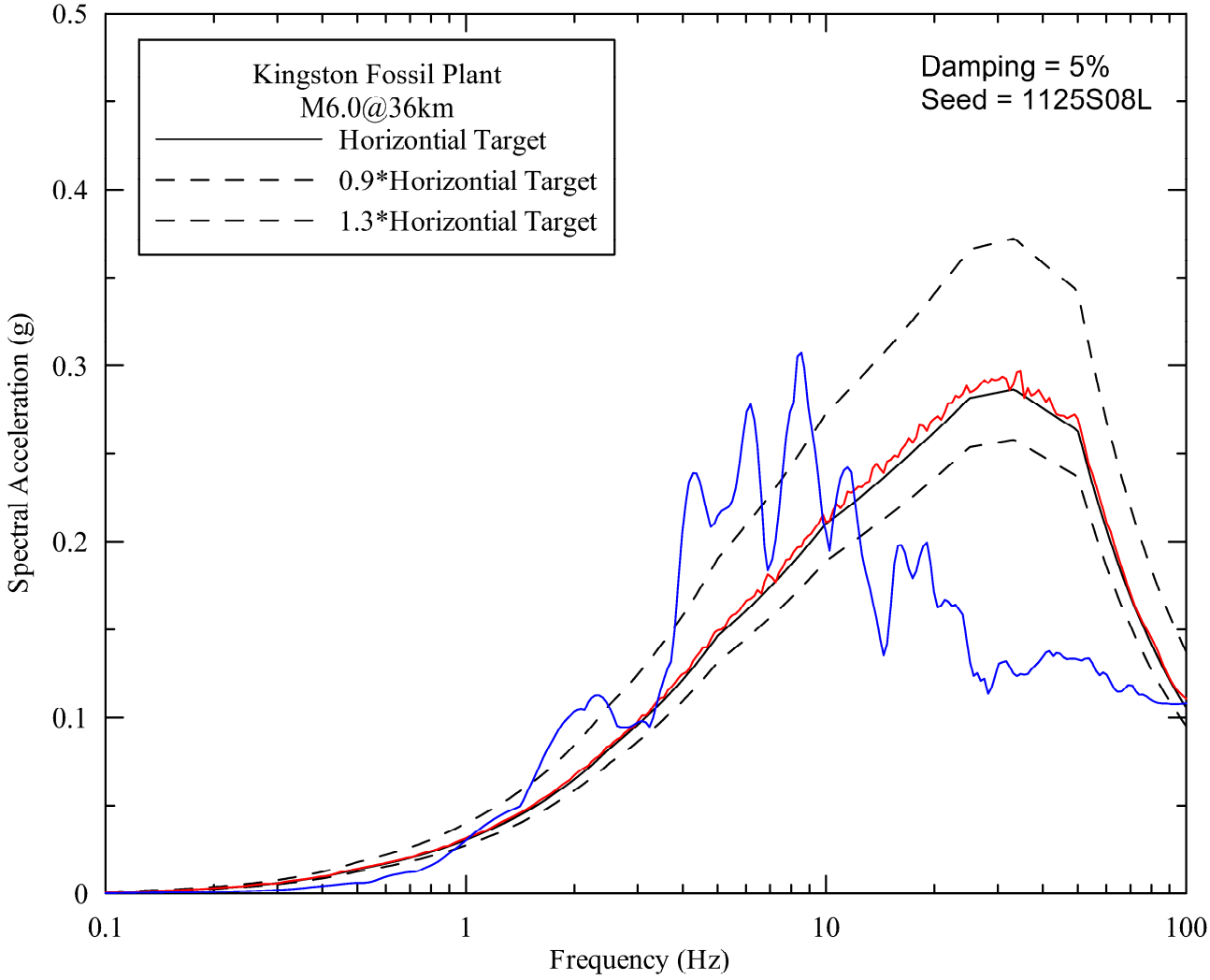
Vertical Target and Matched Response Spectra (7% Damping)
For the M7.6, 435 km Scenario Earthquake

AMEC Geomatrix

Project No: 13452.003

Figure 43

I:\Project\13000\13452.003\12000 CALCS EVALS ANALYSIS\Kingston\Figures\Target_TAP075-V_7%.grf



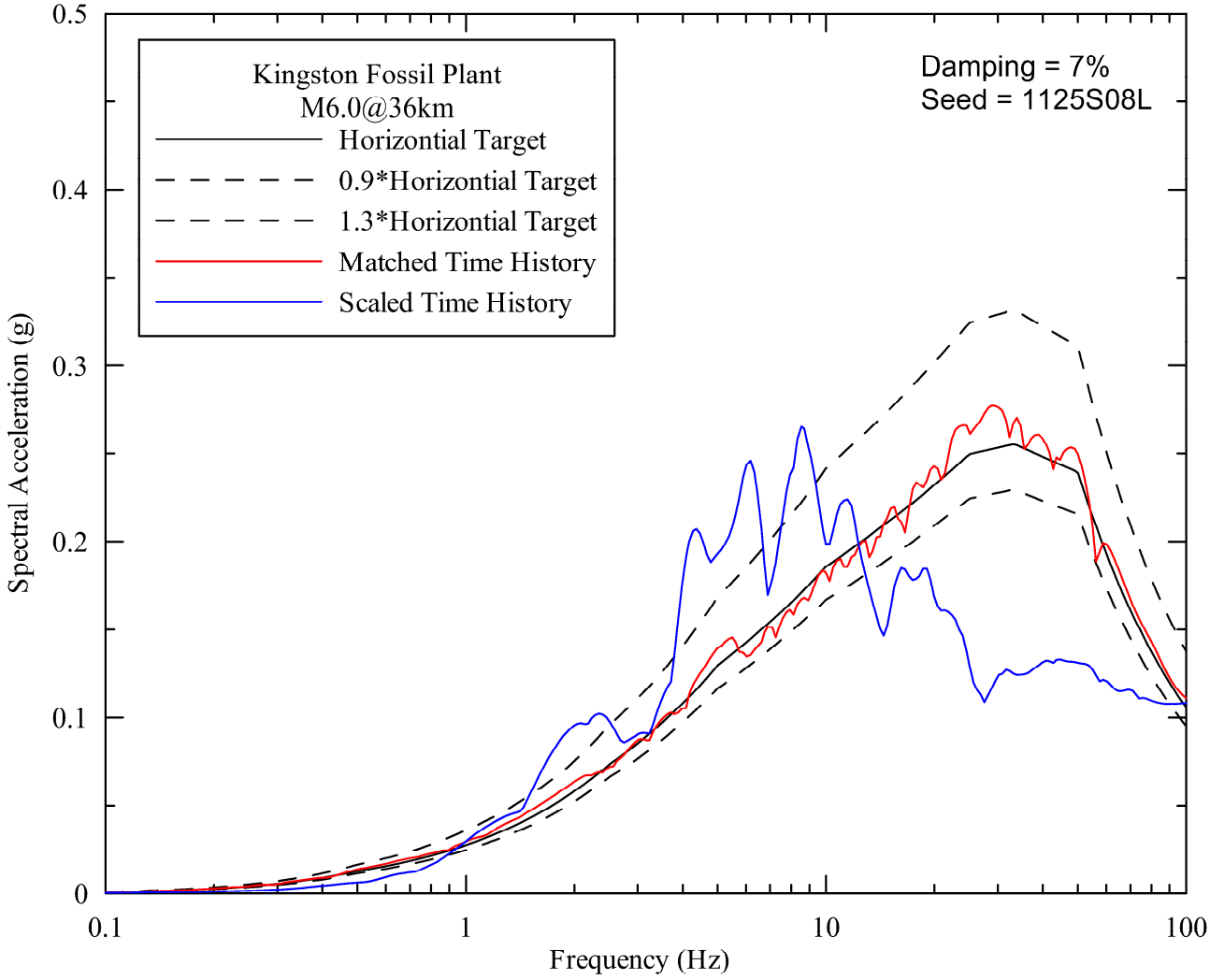
Horizontial Target and Matched Response Spectra (5% Damping)
For the M6.0, 36 km Scenario Earthquake

AMEC Geomatrix

Project No: 13452.003

Figure 44

I:\Project\13000\13452.003\12000 CALCS EVALS ANALYSIS\Kingston\Figures\Target_1125S08L_5%.grf



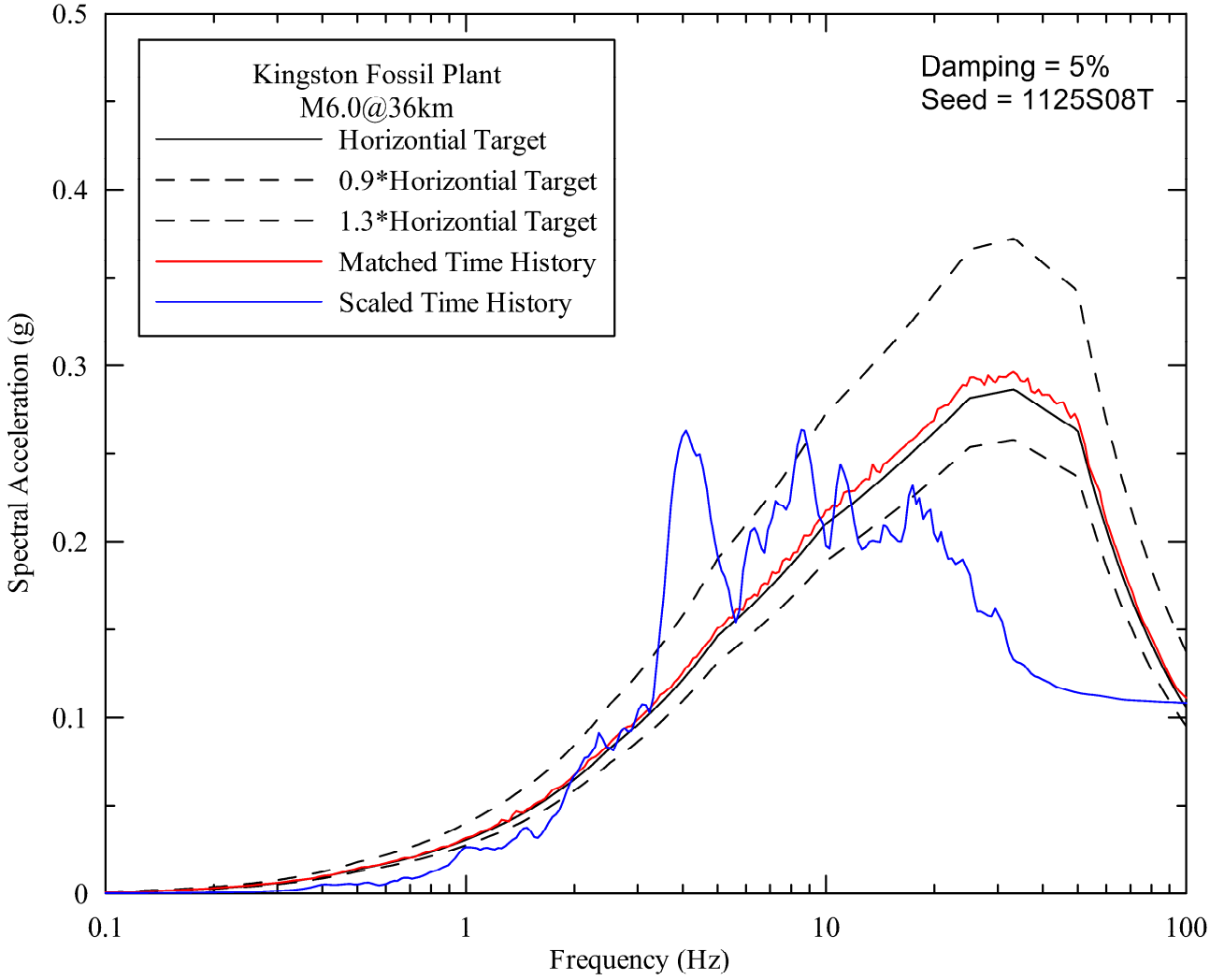
Horizontial Target and Matched Response Spectra (7% Damping)
For the M6.0, 36 km Scenario Earthquake

AMEC Geomatrix

Project No: 13452.003

Figure 45

I:\Project\13000\13452.003\12000 CALCS EVALS ANALYSIS\Kingston\Figures\Target_1125S08L_7%.grf



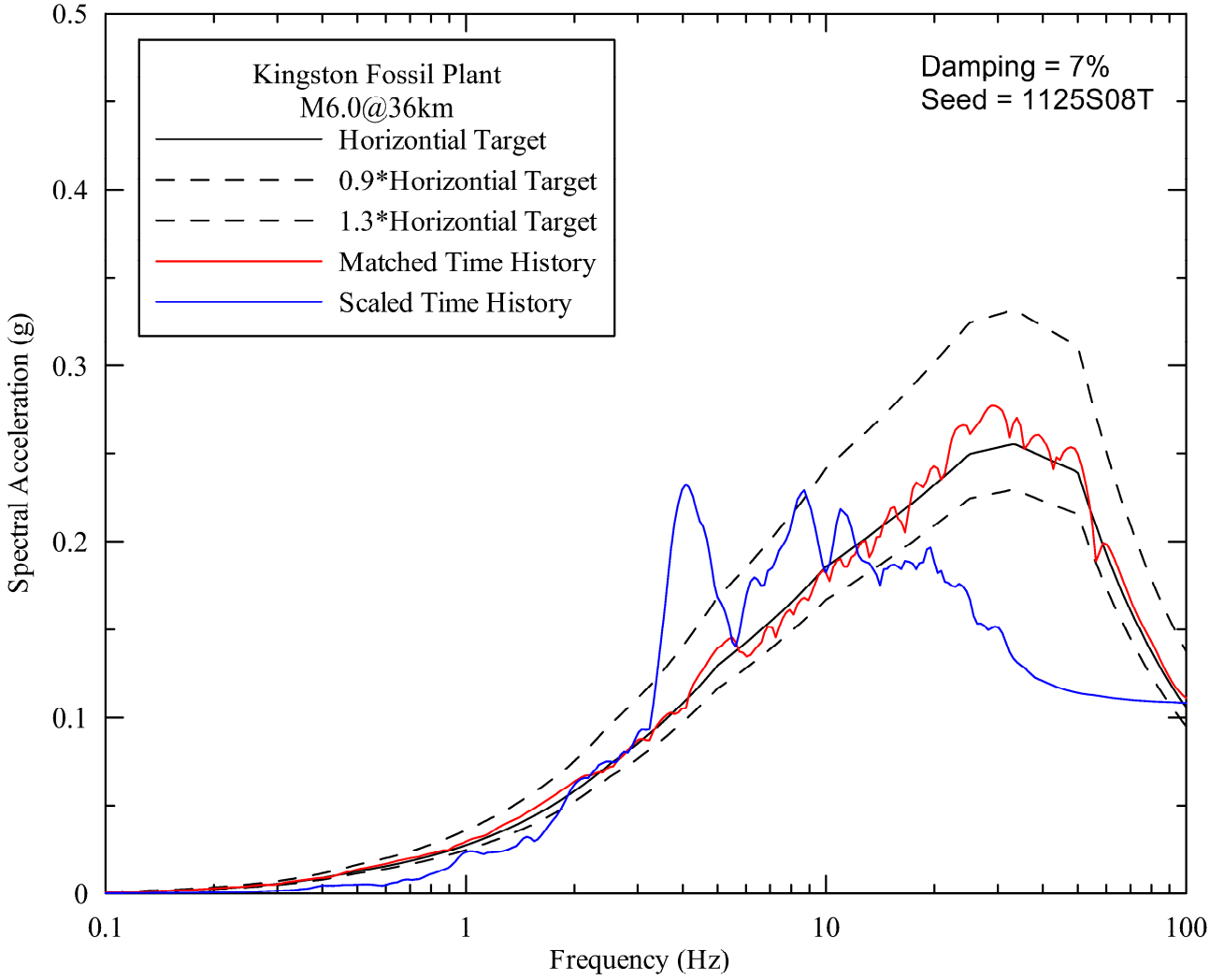
Horizontial Target and Matched Response Spectra (5% Damping)
For the M6.0, 36 km Scenario Earthquake

AMEC Geomatrix

Project No: 13452.003

Figure 46

I:\Project\13000\13452.003\12000 CALCS EVALS ANALYSIS\Kingston\Figures\Target_1125S08T_5%.grf



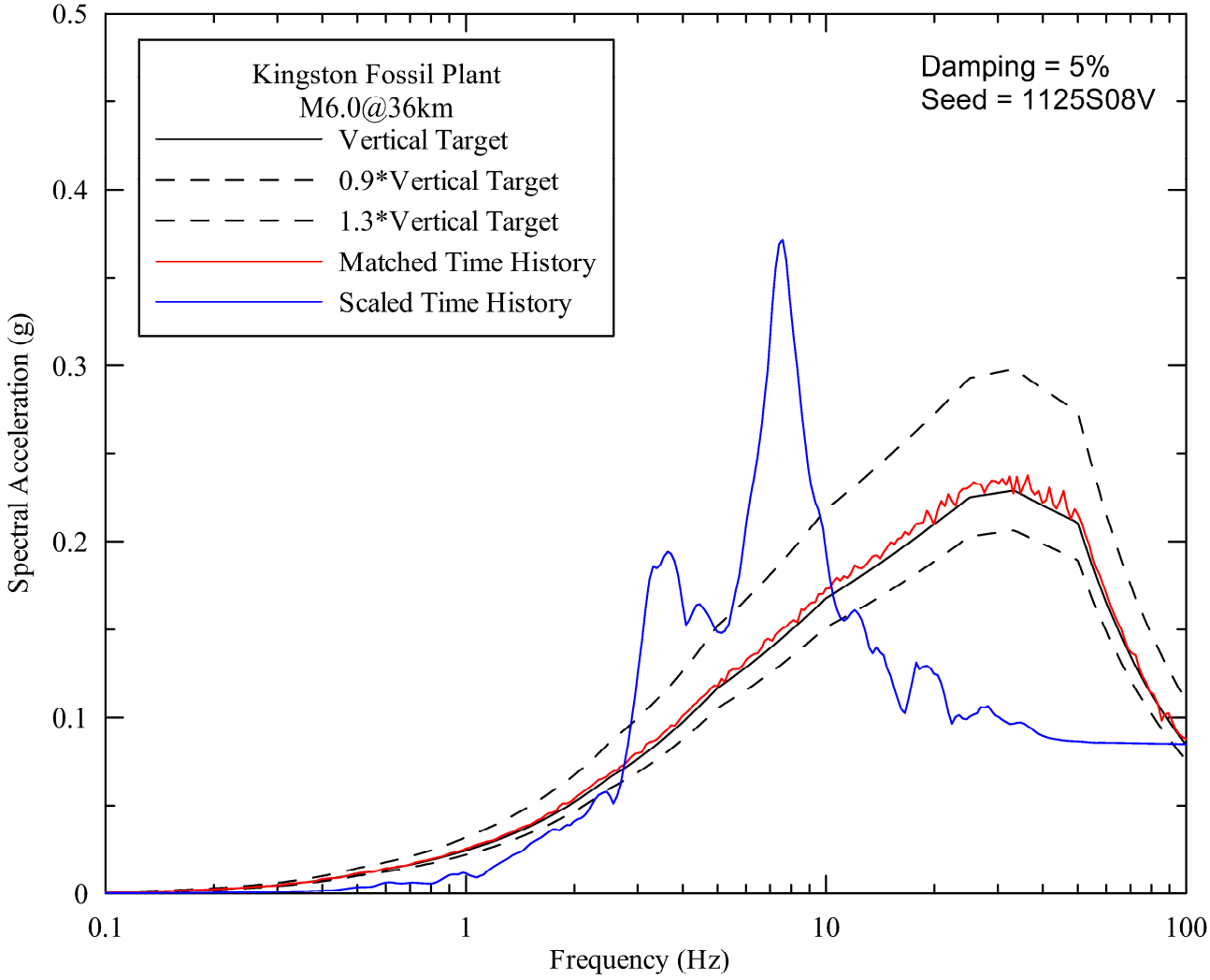
Horizontial Target and Matched Response Spectra (7% Damping)
For the M6.0, 36 km Scenario Earthquake

AMEC Geomatrix

Project No: 13452.003

Figure 47

I:\Project\13000\13452.003\12000 CALCS EVALS ANALYSIS\Kingston\Figures\Target_1125S08T_7%.grf



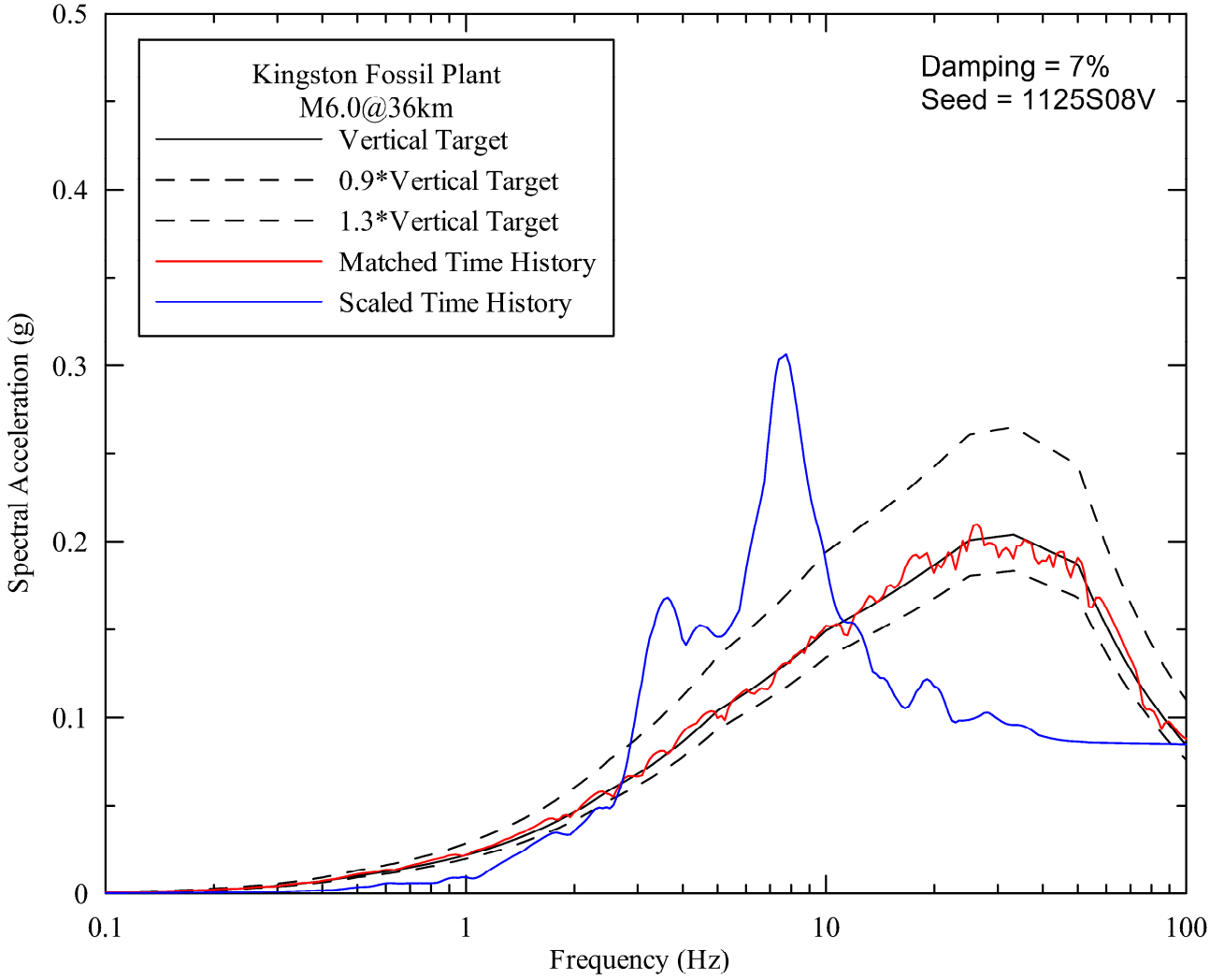
Vertical Target and Matched Response Spectra (5% Damping)
For the M6.0, 26 km Scenario Earthquake

AMEC Geomatrix

Project No: 13452.003

Figure 48

I:\Project\13000\13452.003\12000 CALCS EVALS ANALYSIS\Kingston\Figures\Target_1125S08V_5%.grf



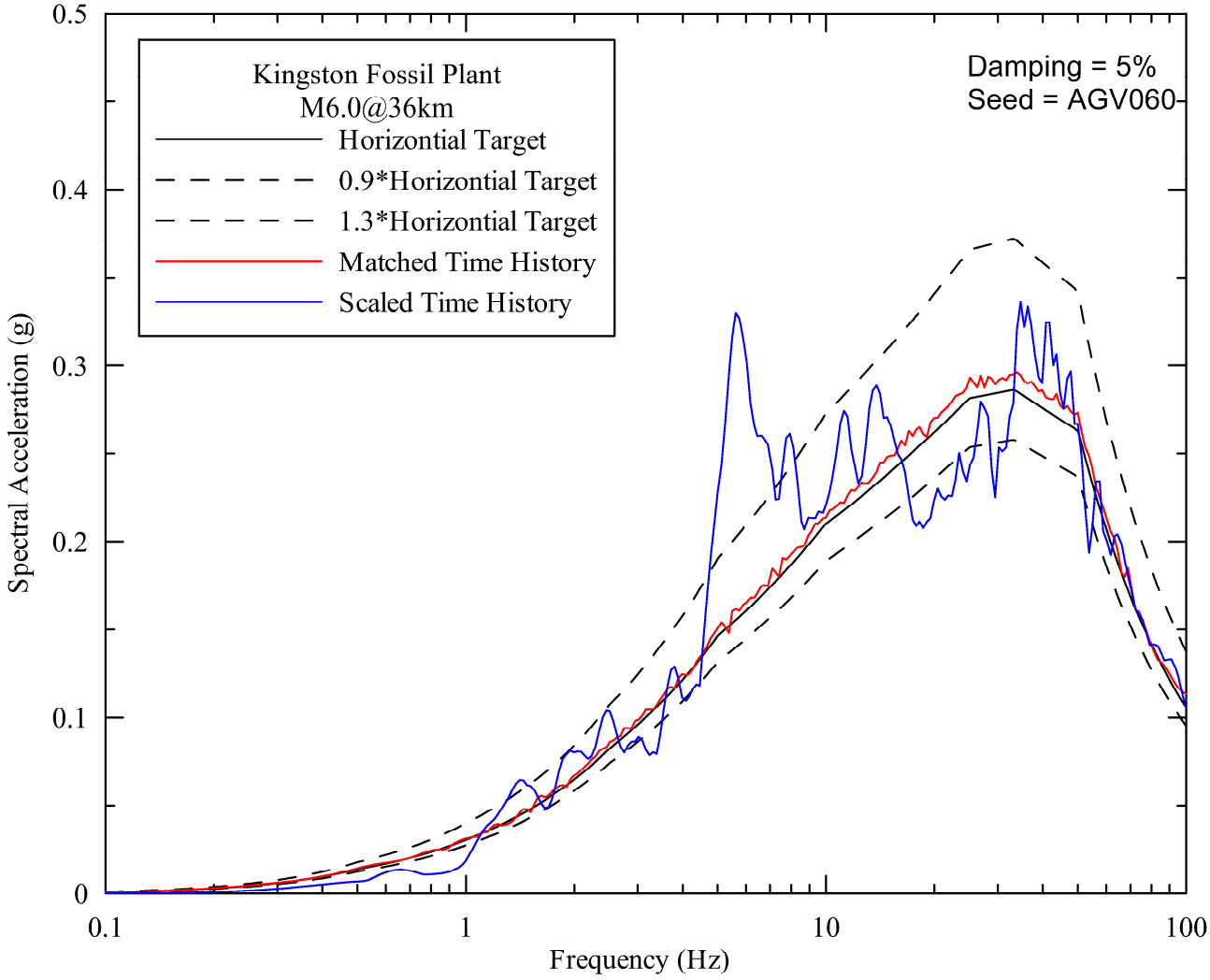
Vertical Target and Matched Response Spectra (7% Damping)
For the M6.0, 26 km Scenario Earthquake

AMEC Geomatrix

Project No: 13452.003

Figure 49

I:\Project\13000\13452.003\12000 CALCS EVALS ANALYSIS\Kingston\Figures\Target_1125S08V_7%.grf



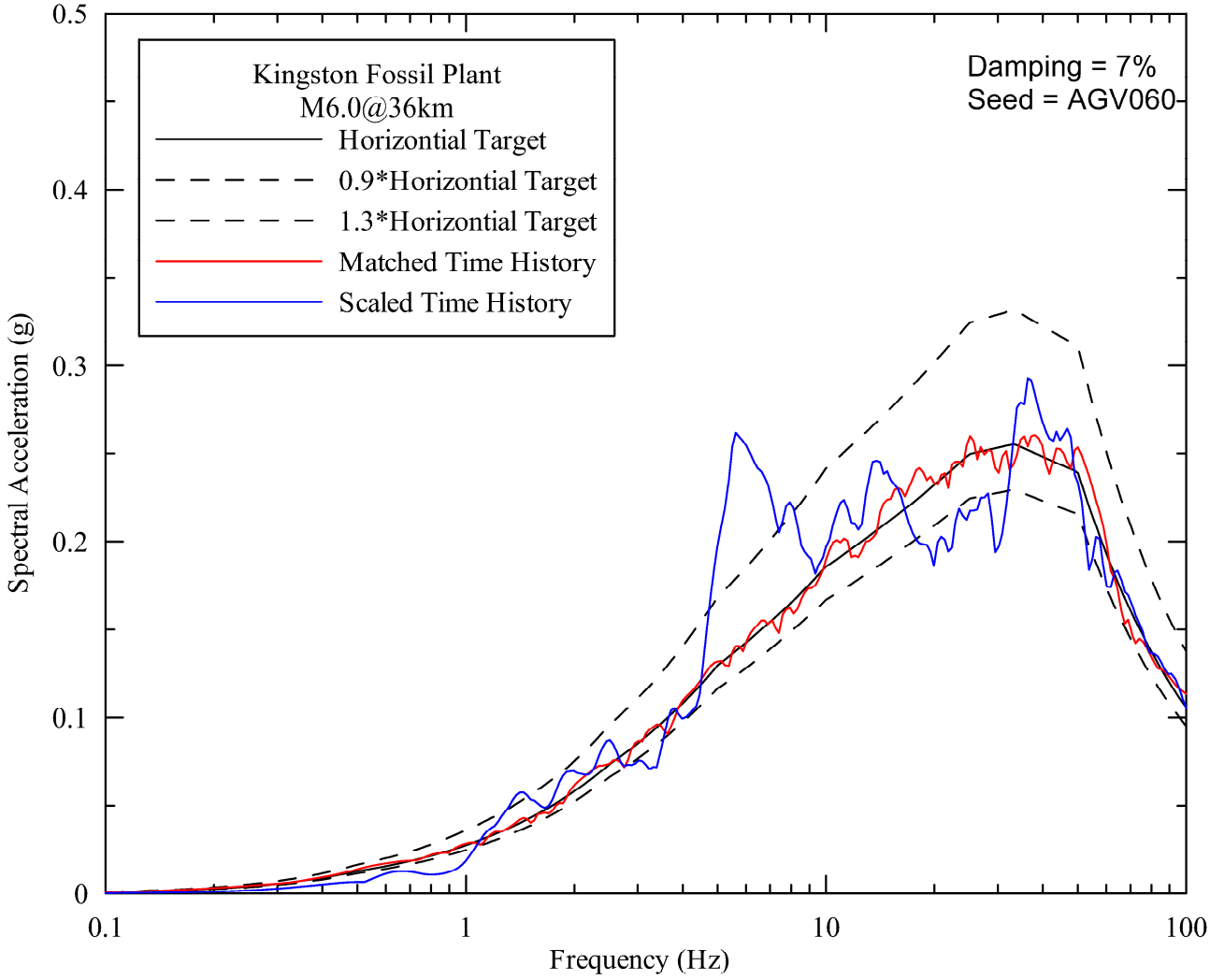
Horizontial Target and Matched Response Spectra (5% Damping)
For the M6.0, 36 km Scenario Earthquake

AMEC Geomatrix

Project No: 13452.003

Figure 50

I:\Project\13000\13452.003\12000 CALCS EVALS ANALYSIS\Kingston\Figures\Target_AGV060_3_5%.grf



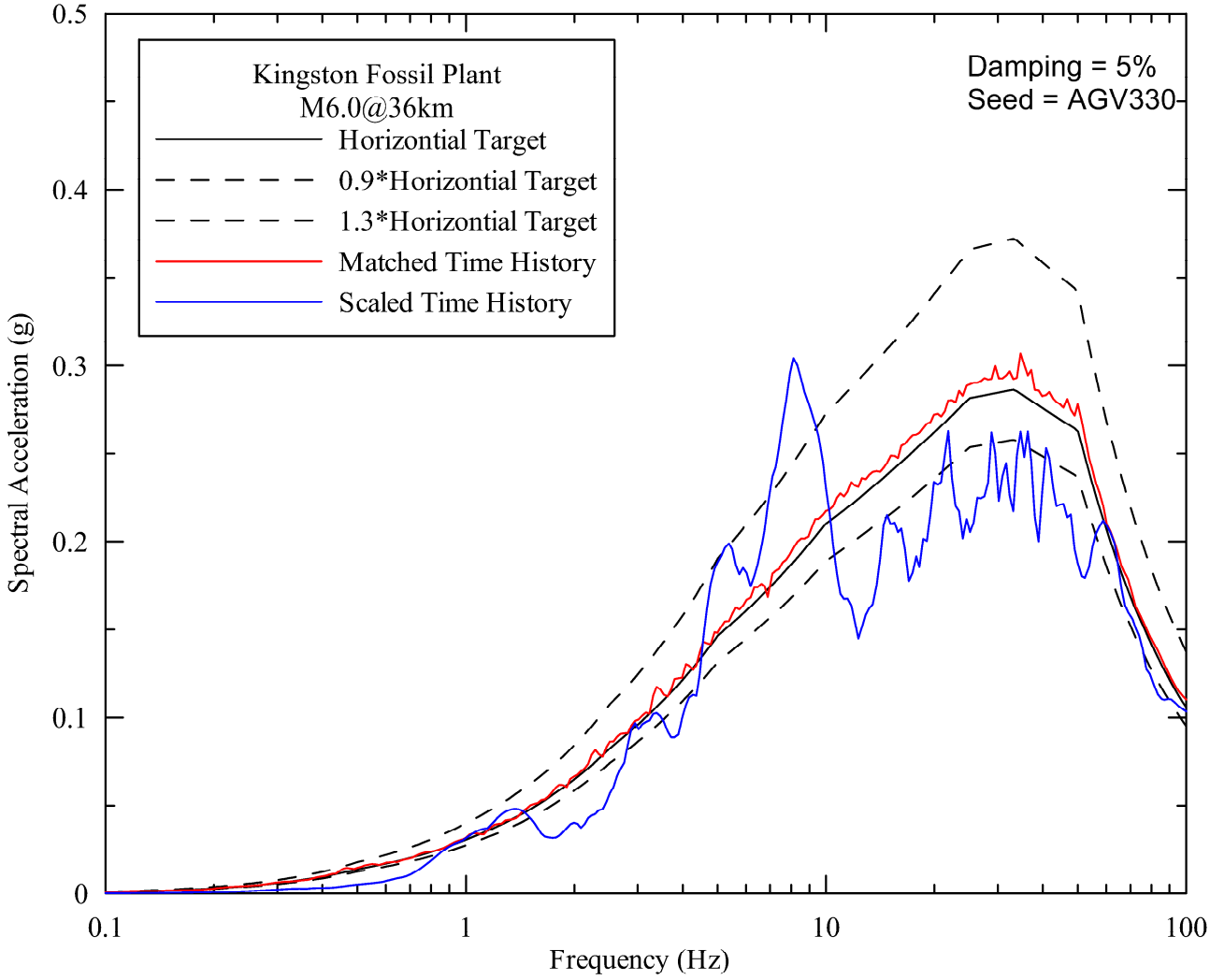
Horizontial Target and Matched Response Spectra (7% Damping)
For the M6.0, 36 km Scenario Earthquake

AMEC Geomatrix

Project No: 13452.003

Figure 51

I:\Project\13000\13452.003\12000 CALCS EVALS ANALYSIS\Kingston\Figures\Target_AGV060_3_7%.grf



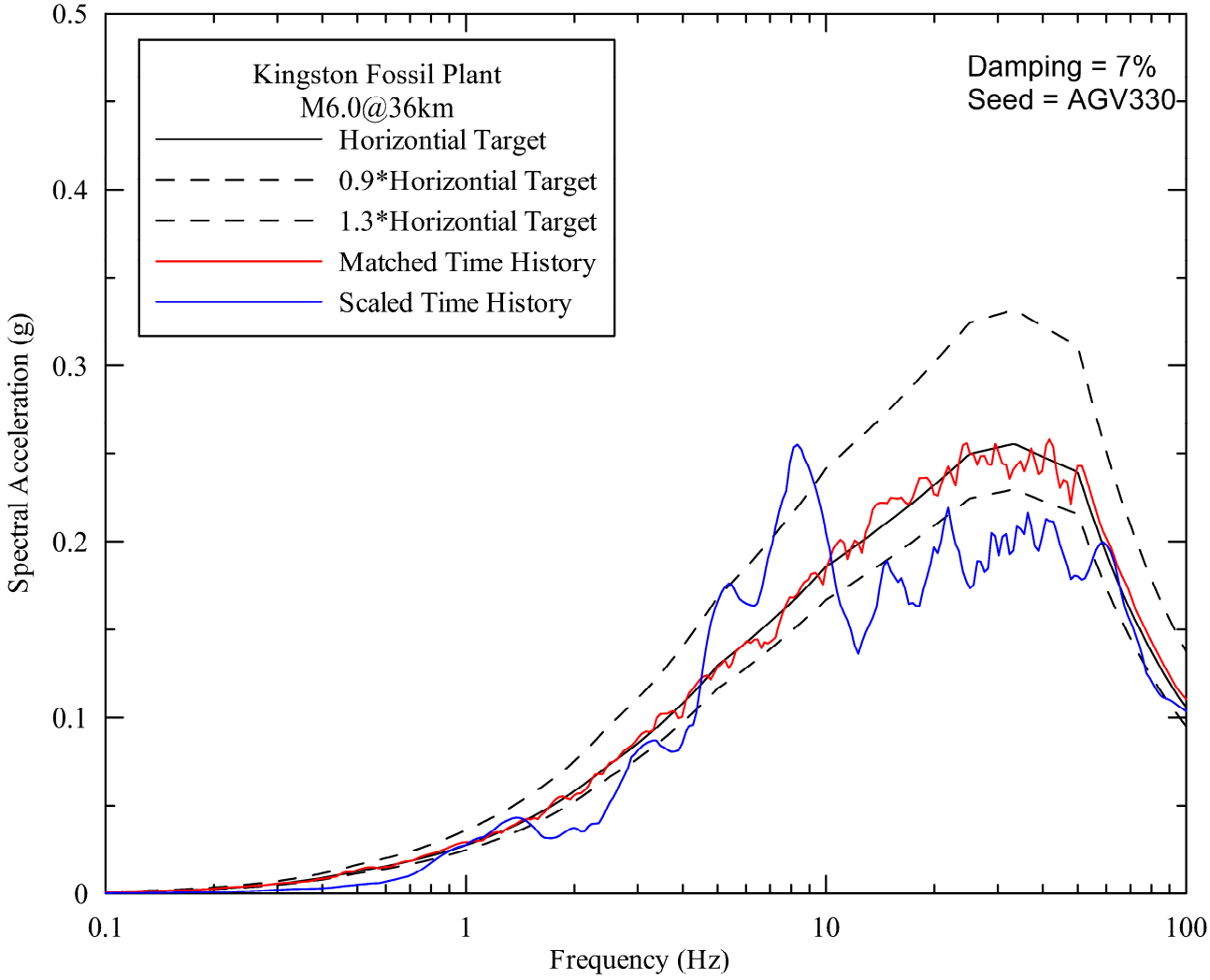
Horizontial Target and Matched Response Spectra (5% Damping)
For the M6.0, 36 km Scenario Earthquake

AMEC Geomatrix

Project No: 13452.003

Figure 52

I:\Project\13000\13452.003\12000 CALCS EVALS ANALYSIS\Kingston\Figures\Target_AGV330_3_5%.grf



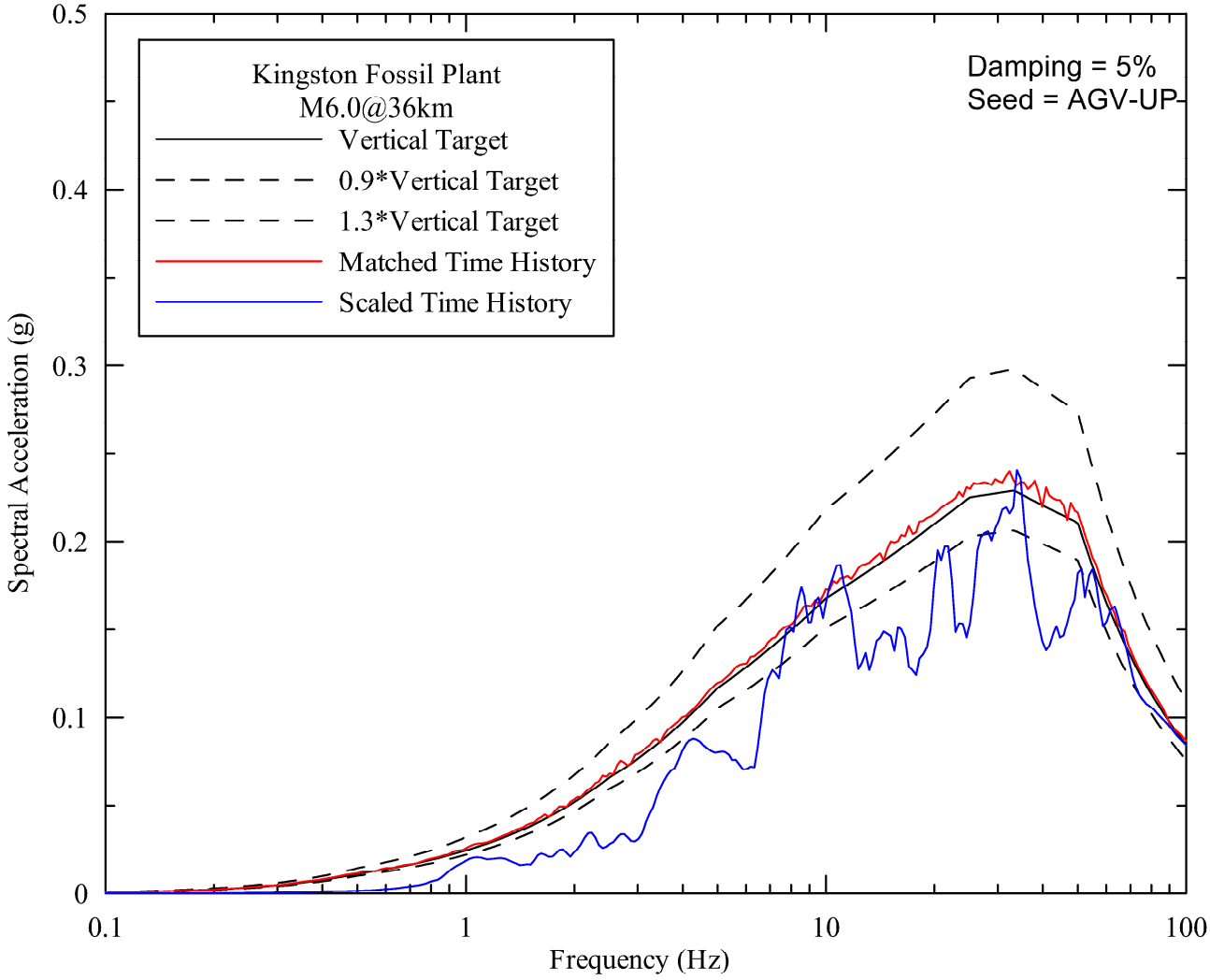
Horizontial Target and Matched Response Spectra (7% Damping)
For the M6.0, 36 km Scenario Earthquake

AMEC Geomatrix

Project No: 13452.003

Figure 53

I:\Project\13000\13452.003\12000 CALCS EVALS ANALYSIS\Kingston\Figures\Target_AGV330_3_7%.grf



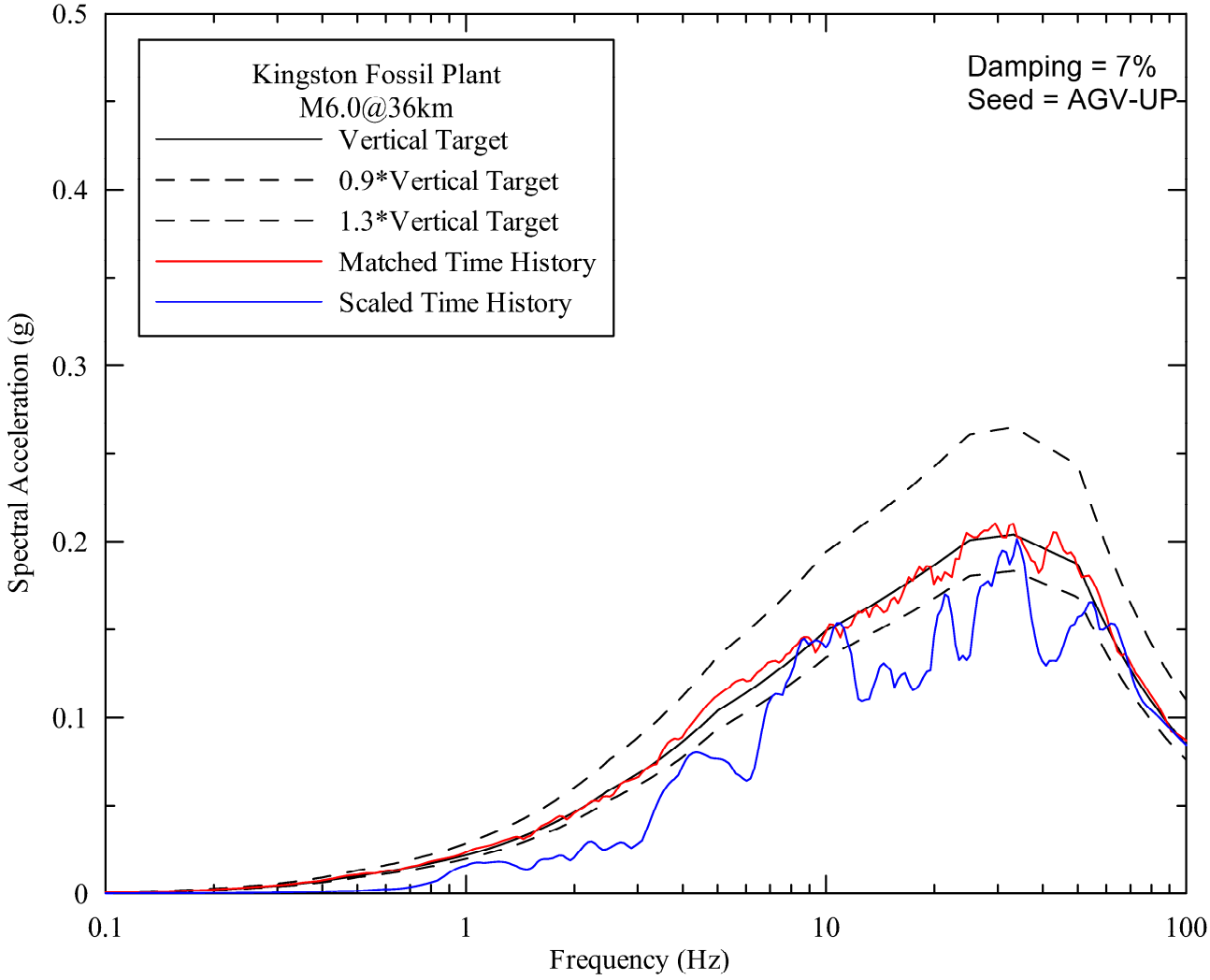
Vertical Target and Matched Response Spectra (5% Damping)
For the M6.0, 26 km Scenario Earthquake

AMEC Geomatrix

Project No: 13452.003

Figure 54

I:\Project\13000\13452.003\12000 CALCS EVALS ANALYSIS\Kingston\Figures\Target_AGV-UP_3_5%.grf



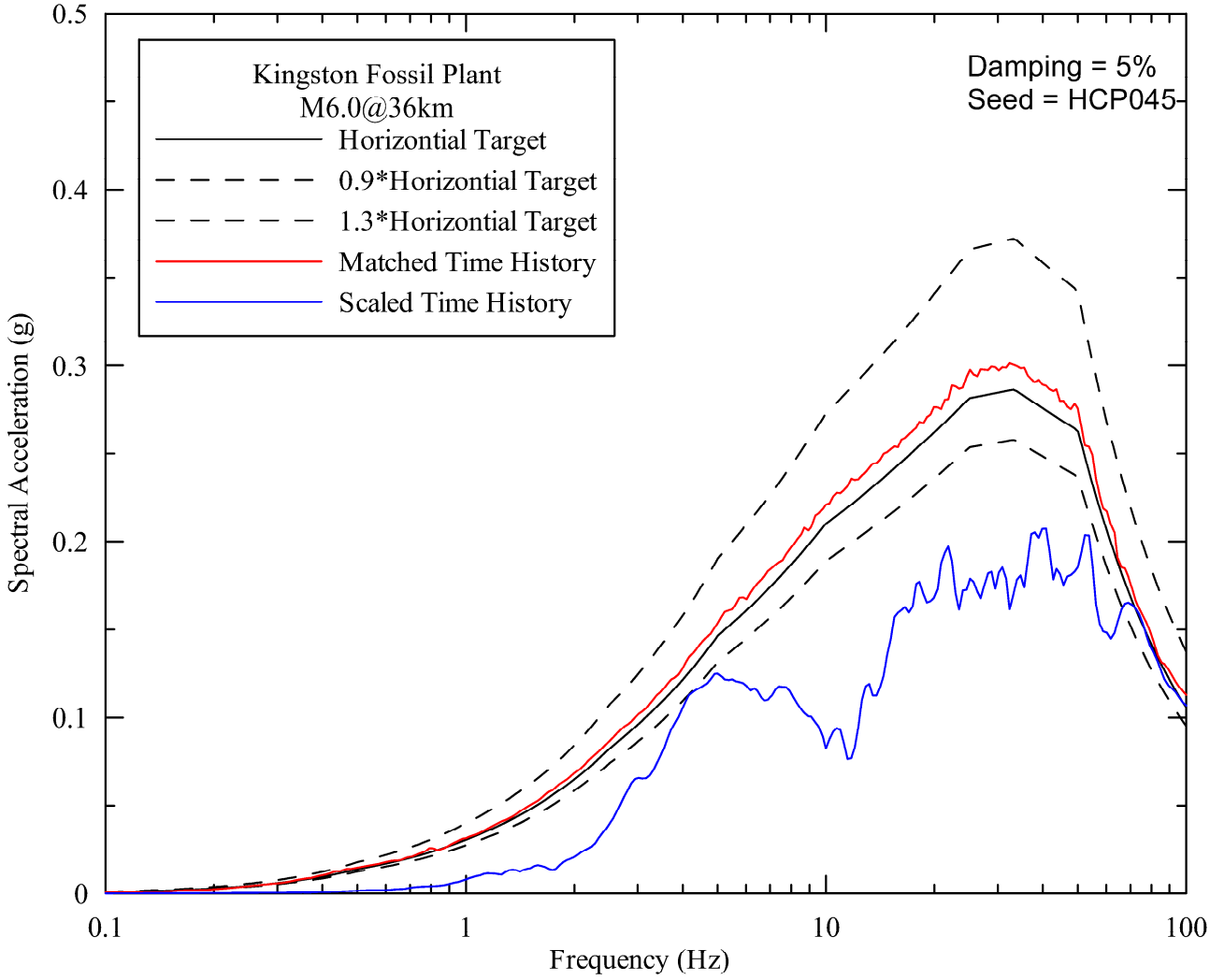
Vertical Target and Matched Response Spectra (7% Damping)
For the M6.0, 36 km Scenario Earthquake

AMEC Geomatrix

Project No: 13452.003

Figure 55

I:\Project\13000\13452.003\12000 CALCS EVALS ANALYSIS\Kingston\Figures\Target_AGV-UP_3_7%.grf



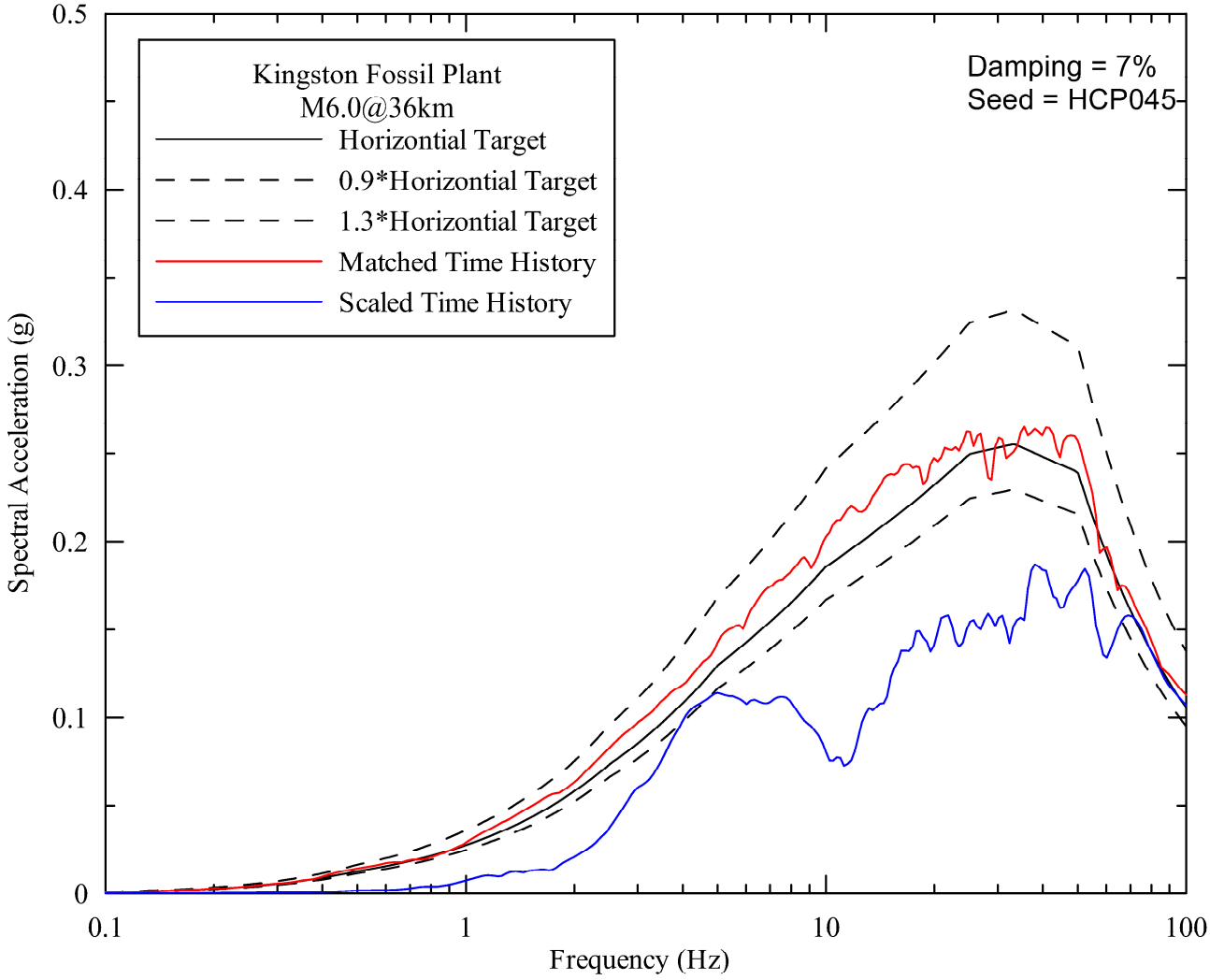
Horizontial Target and Matched Response Spectra (5% Damping)
For the M6.0, 36 km Scenario Earthquake

AMEC Geomatrix

Project No: 13452.003

Figure 56

I:\Project\13000\13452.003\12000 CALCS EVALS ANALYSIS\Kingston\Figures\Target_HCP045_3_5%.grf



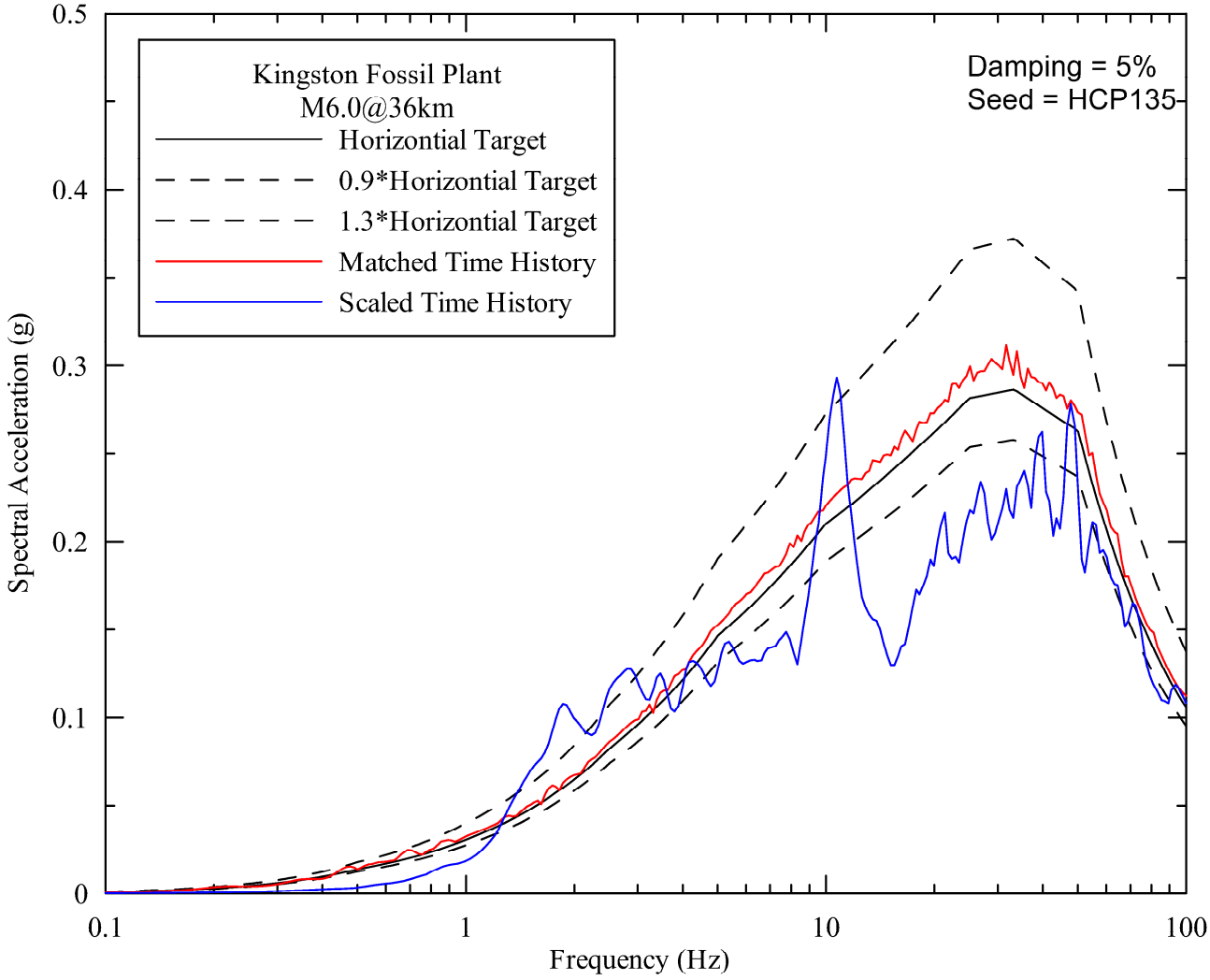
Horizontial Target and Matched Response Spectra (7% Damping)
For the M6.0, 36 km Scenario Earthquake

AMEC Geomatrix

Project No: 13452.003

Figure 57

I:\Project\13000\13452.003\12000 CALCS EVALS ANALYSIS\Kingston\Figures\Target_HCP045_3_7%.grf



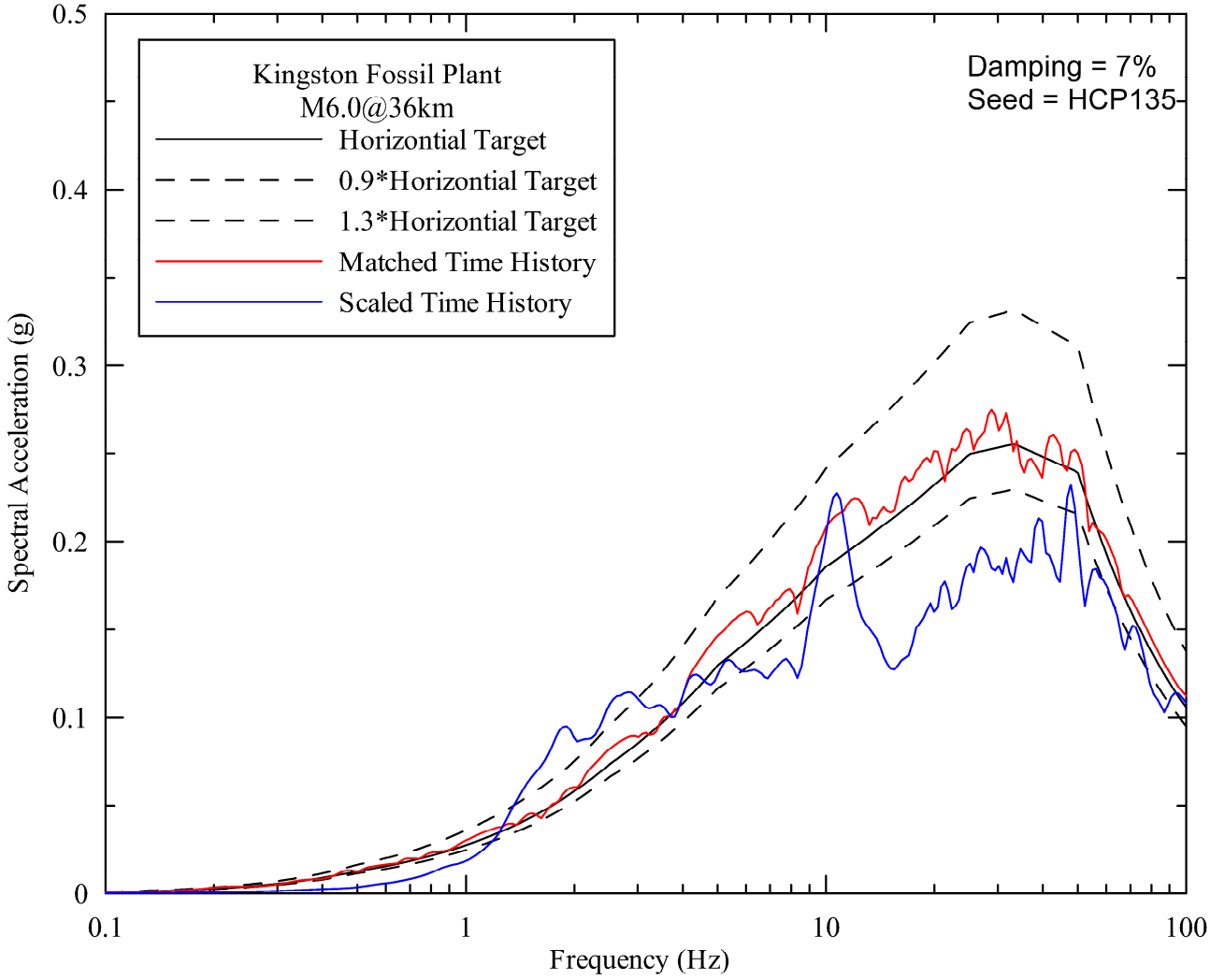
Horizontial Target and Matched Response Spectra (5% Damping)
For the M6.0, 36 km Scenario Earthquake

AMEC Geomatrix

Project No: 13452.003

Figure 58

I:\Project\13000\13452.003\12000 CALCS EVALS ANALYSIS\Kingston\Figures\Target_HCP135_3_5%.grf



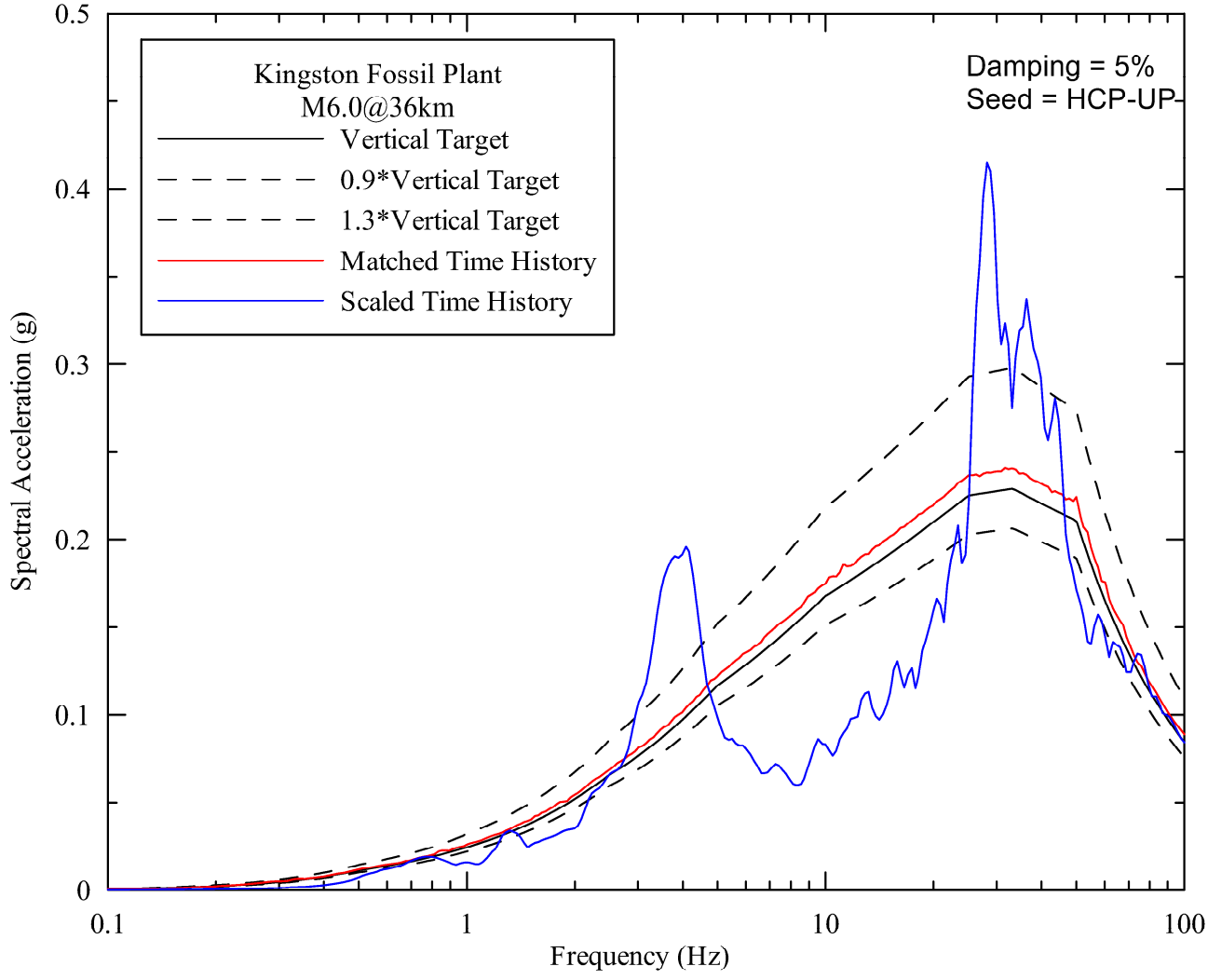
Horizontial Target and Matched Response Spectra (7% Damping)
For the M6.0, 36 km Scenario Earthquake

AMEC Geomatrix

Project No: 13452.003

Figure 59

I:\Project\13000\13452.003\12000 CALCS EVALS ANALYSIS\Kingston\Figures\Target_HCP135_3_7%.grf



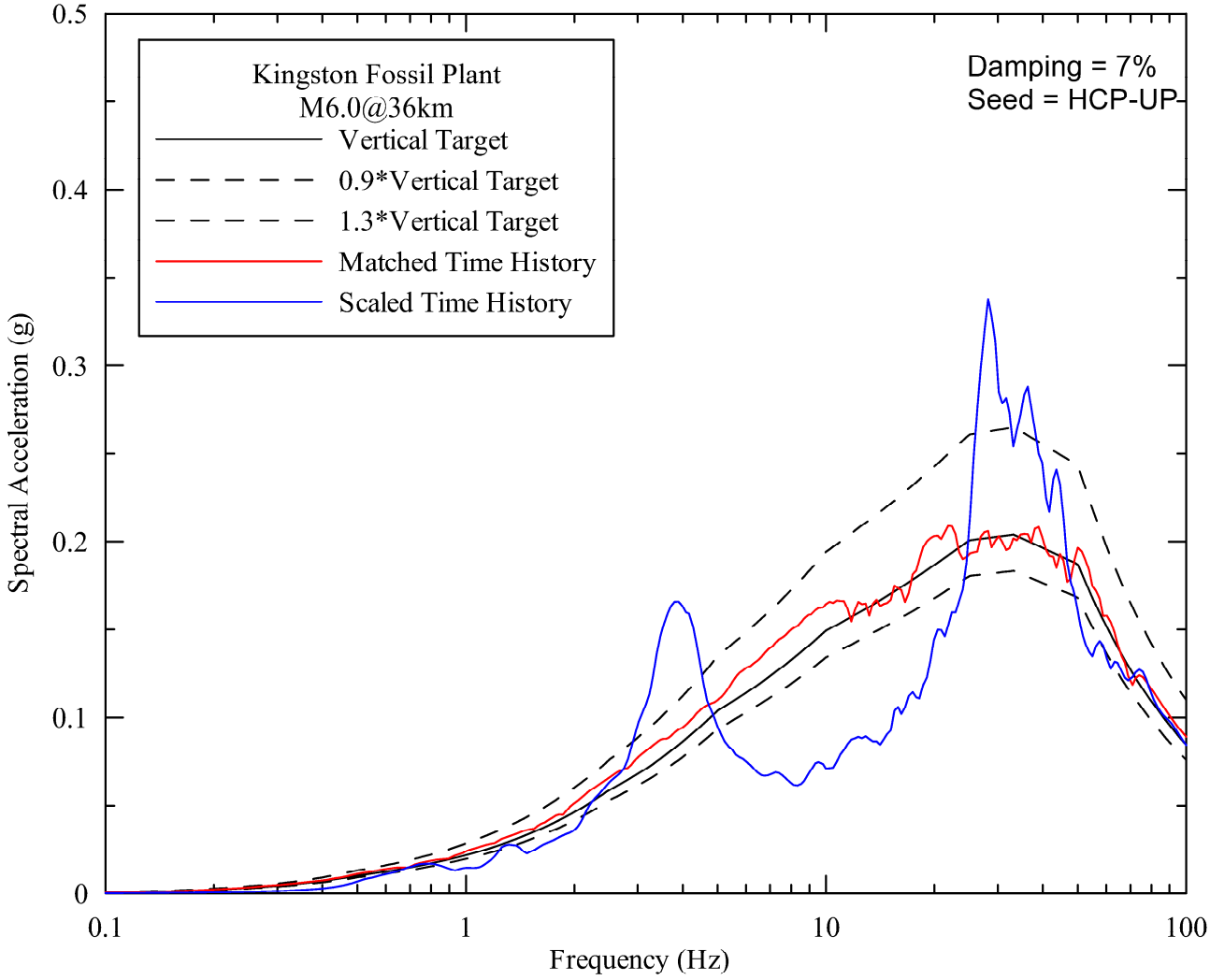
Vertical Target and Matched Response Spectra (5% Damping)
For the M6.0, 26 km Scenario Earthquake

AMEC Geomatrix

Project No: 13452.003

Figure 60

I:\Project\13000\13452.003\12000 CALCS EVALS ANALYSIS\Kingston\Figures\Target_HCP-UP_3_5%.grf



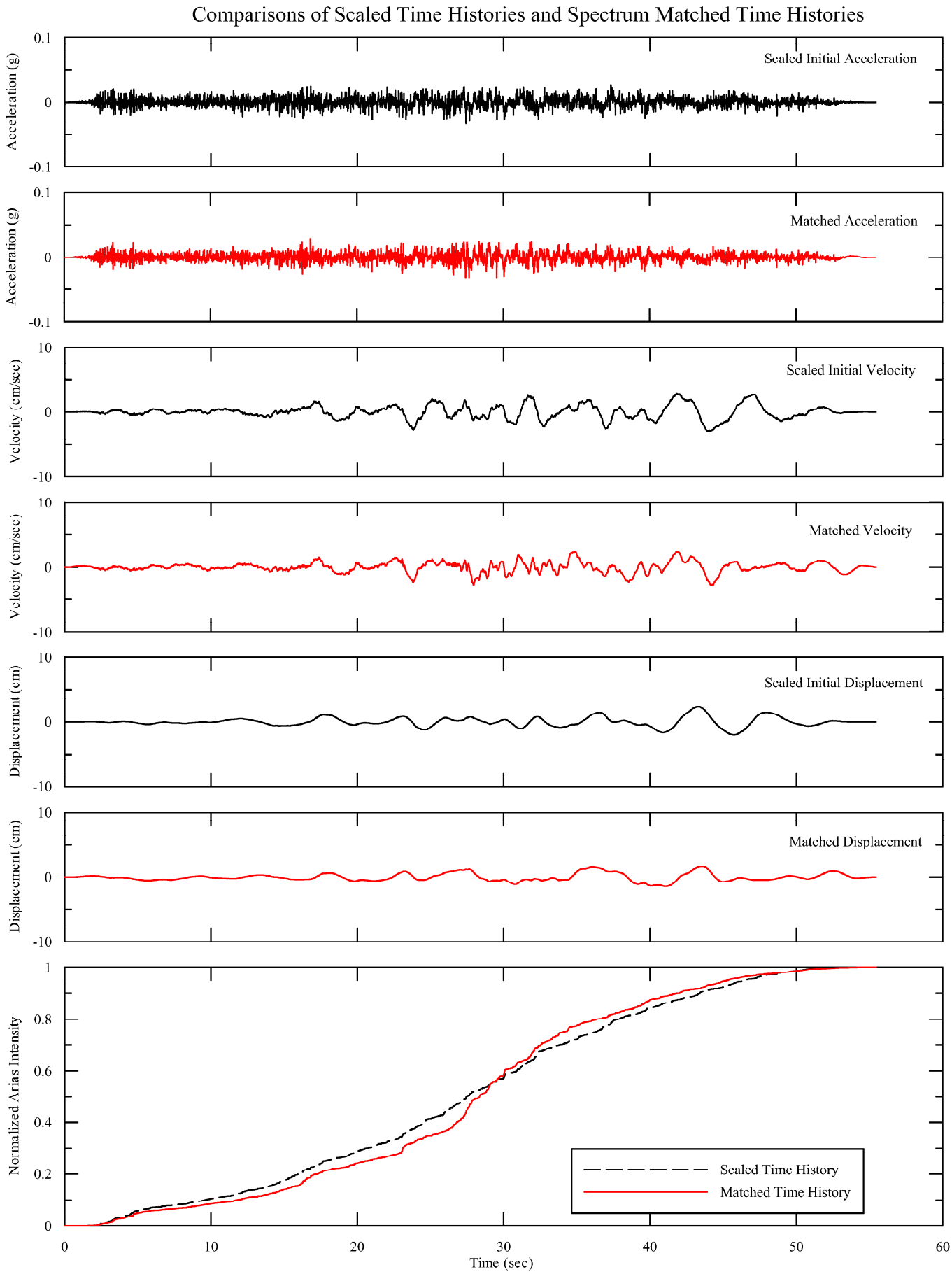
Vertical Target and Matched Response Spectra (7% Damping)
For the M6.0, 36 km Scenario Earthquake

AMEC Geomatrix

Project No: 13452.003

Figure 61

I:\Project\13000\13452.003\12000 CALCS EVALS ANALYSIS\Kingston\Figures\Target_HCP-UP_3_7%.grf

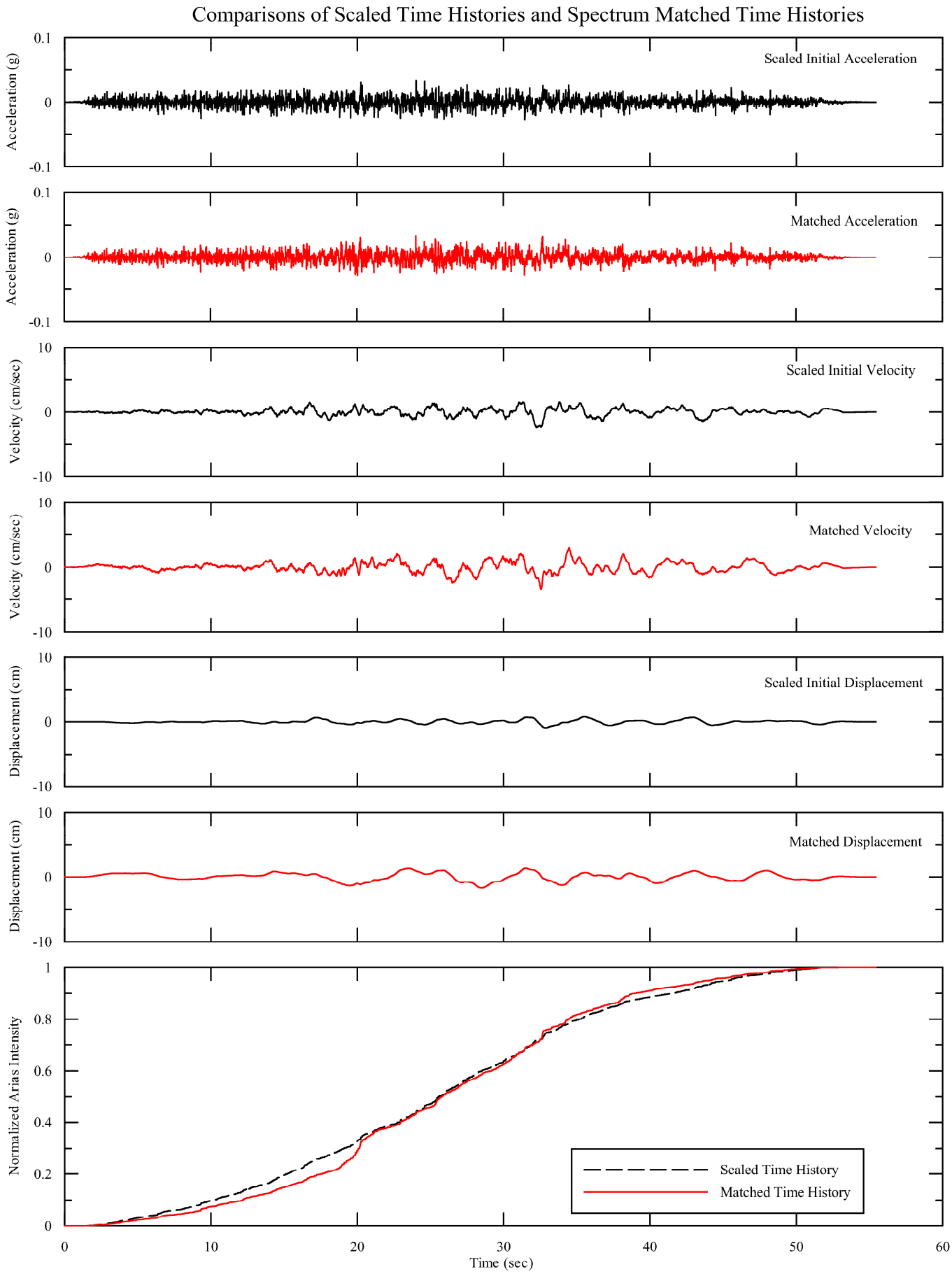


Seed Motion: 1992 Landers Earthquake, SER000 Station,
Match to Horizontal Target Spectrum

AMEC Geomatrix

Figure 62

I:\Project\13000\13452.003\12000 CALCS EVALS ANALYSIS\Kingston\Figures\SER000_3_final.grf

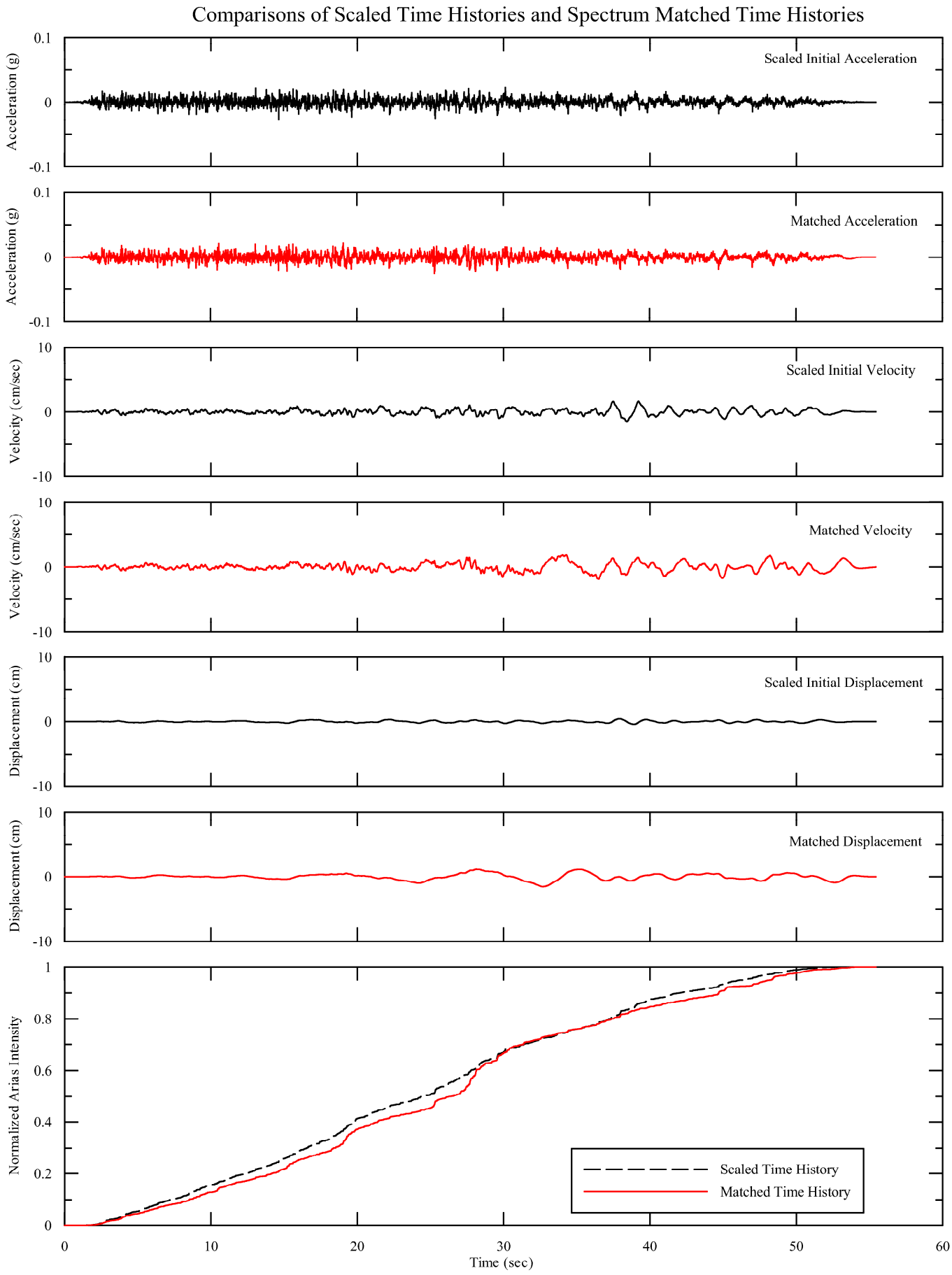


Seed Motion: 1992 Landers Earthquake, SER270 Station,
Match to Horizontal Target Spectrum

AMEC Geomatrix

Figure 63

I:\Project\13000\13452.003\12000 CALCS EVALS ANALYSIS\Kingston\Figures\SER270_3_final.grf

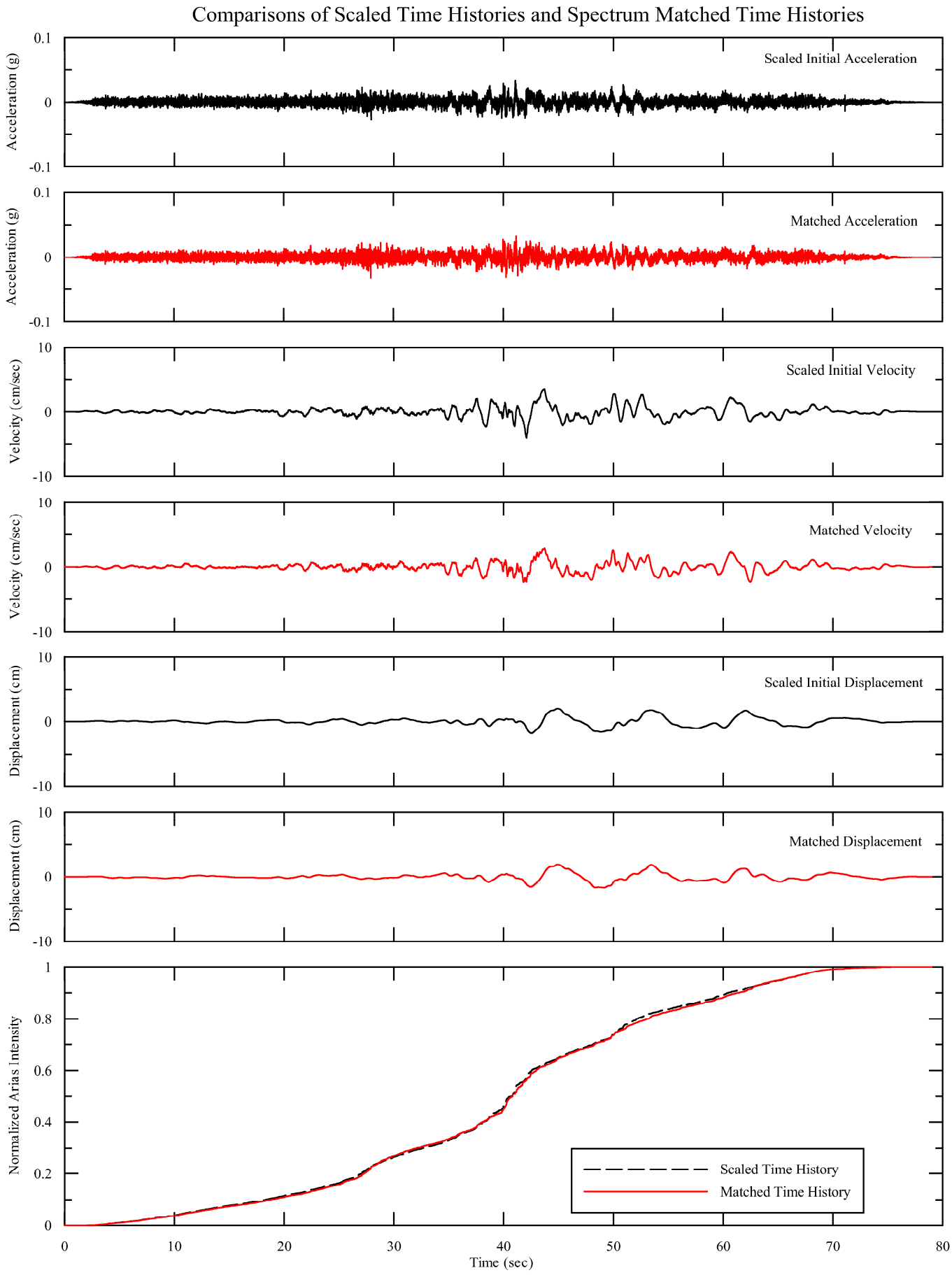


Seed Motion: 1992 Landers Earthquake, SER-UP Station,
Match to Horizontal Target Spectrum

AMEC Geomatrix

Figure 64

I:\Project\13000\13452.003\12000 CALCS EVALS ANALYSIS\Kingston\Figures\SER-UP_3_final.grf

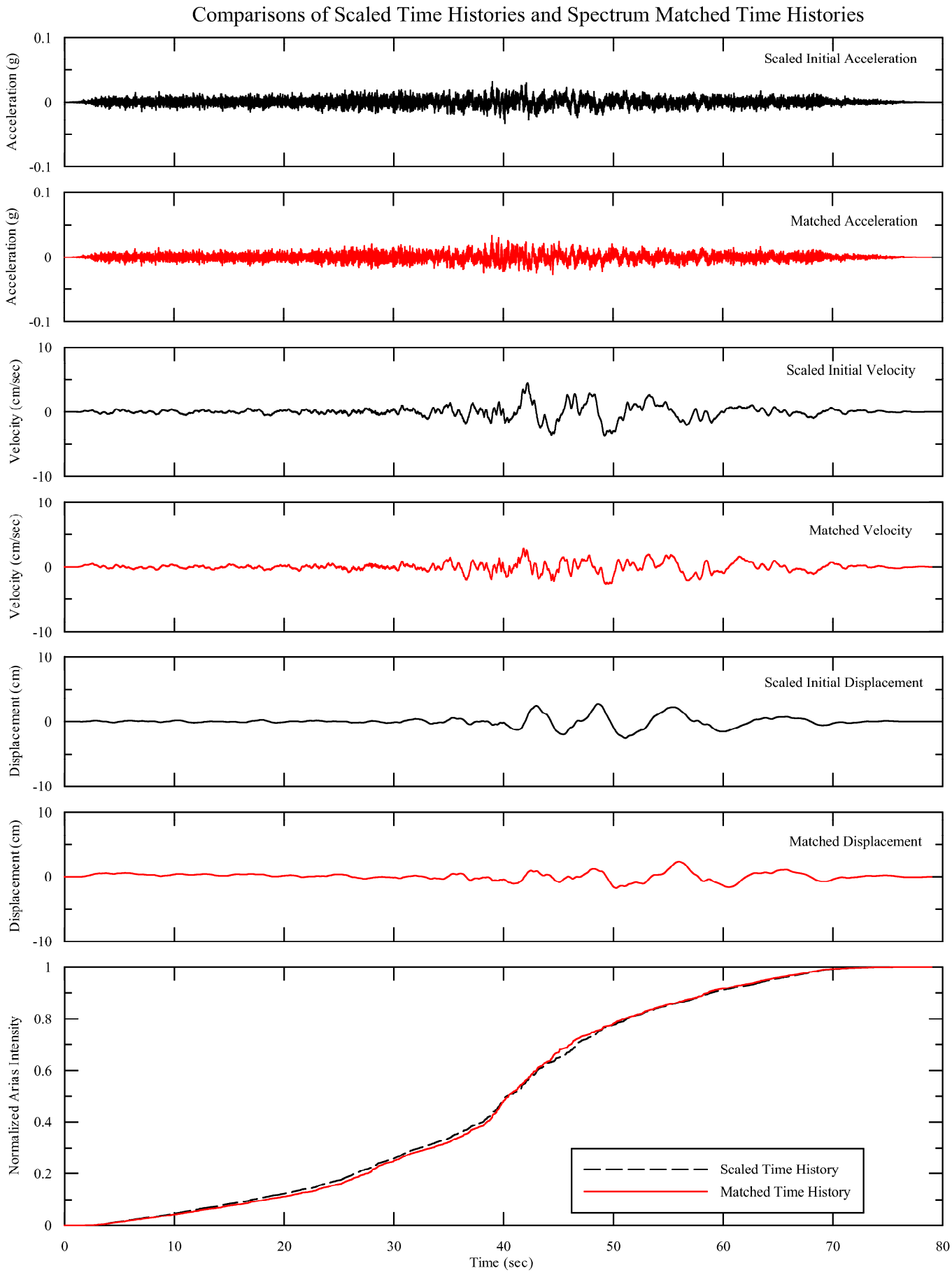


Seed Motion: 1999 ChiChi Earthquake, TAP067-N Station,
Match to Horizontal Target Spectrum

AMEC Geomatrix

Figure 65

I:\Project\13000\13452.003\12000 CALCS EVALS ANALYSIS\Kingston\Figures\TAP067-N_3_final.grf

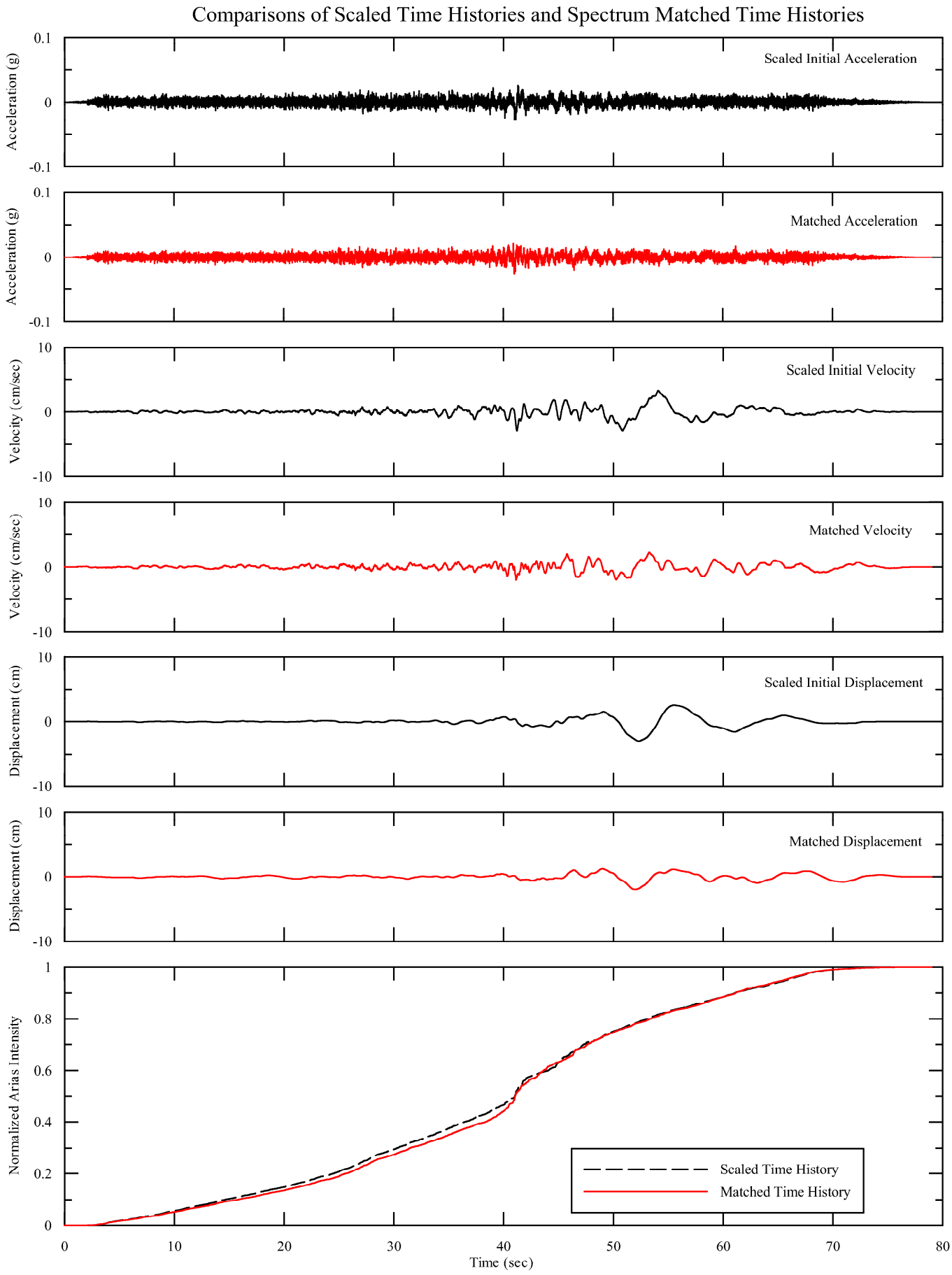


Seed Motion: 1999 ChiChi Earthquake, TAP067-W Station,
Match to Horizontal Target Spectrum

AMEC Geomatrix

Figure 66

I:\Project\13000\13452.003\12000 CALCS EVALS ANALYSIS\Kingston\Figures\TAP067-W_3_final.grf

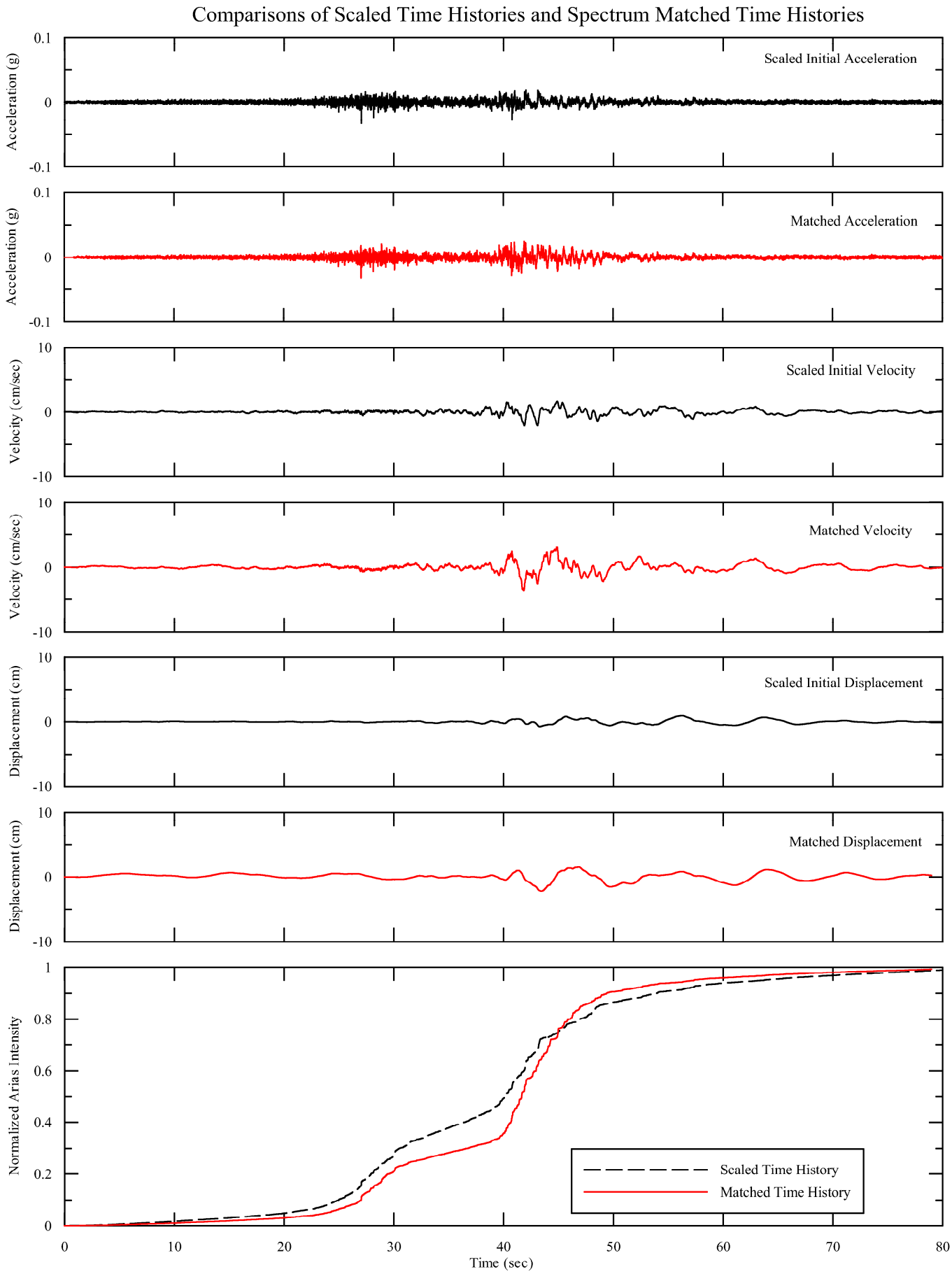


Seed Motion: 1999 ChiChi Earthquake, ILA031-V Station,
Match to Vertical Target Spectrum

AMEC Geomatrix

Figure 67

I:\Project\13000\13452.003\12000 CALCS EVALS ANALYSIS\Kingston\Figures\TAP067-V_3_final.grf

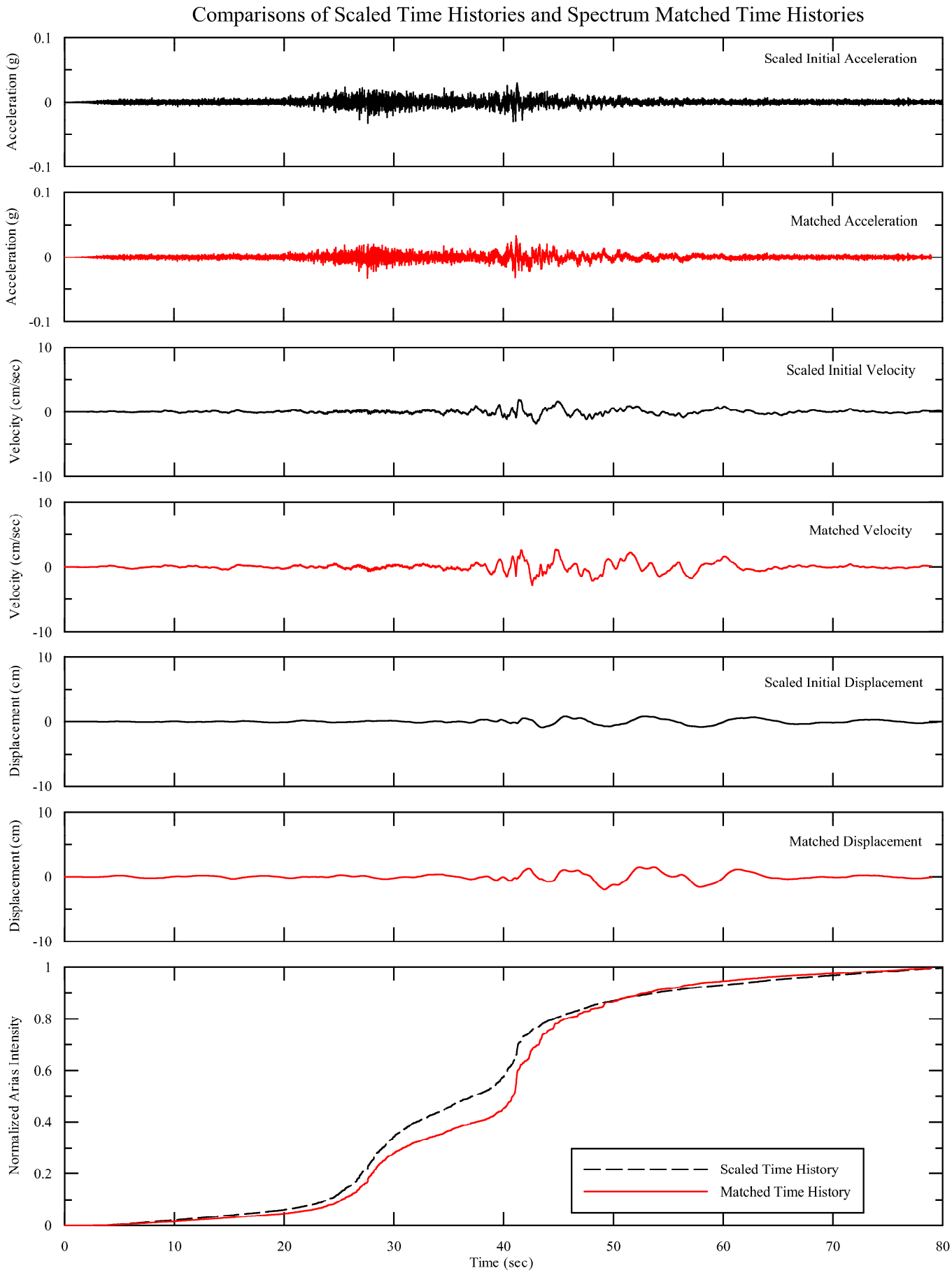


Seed Motion: 1999 Chi-Chi Earthquake, TAP075-N Station,
Match to Horizontal Target Spectrum

AMEC Geomatrix

Figure 68

I:\Project\13000\13452.003\12000 CALCS EVALS ANALYSIS\Kingston\Figures\TAP075-N_3_final.grf

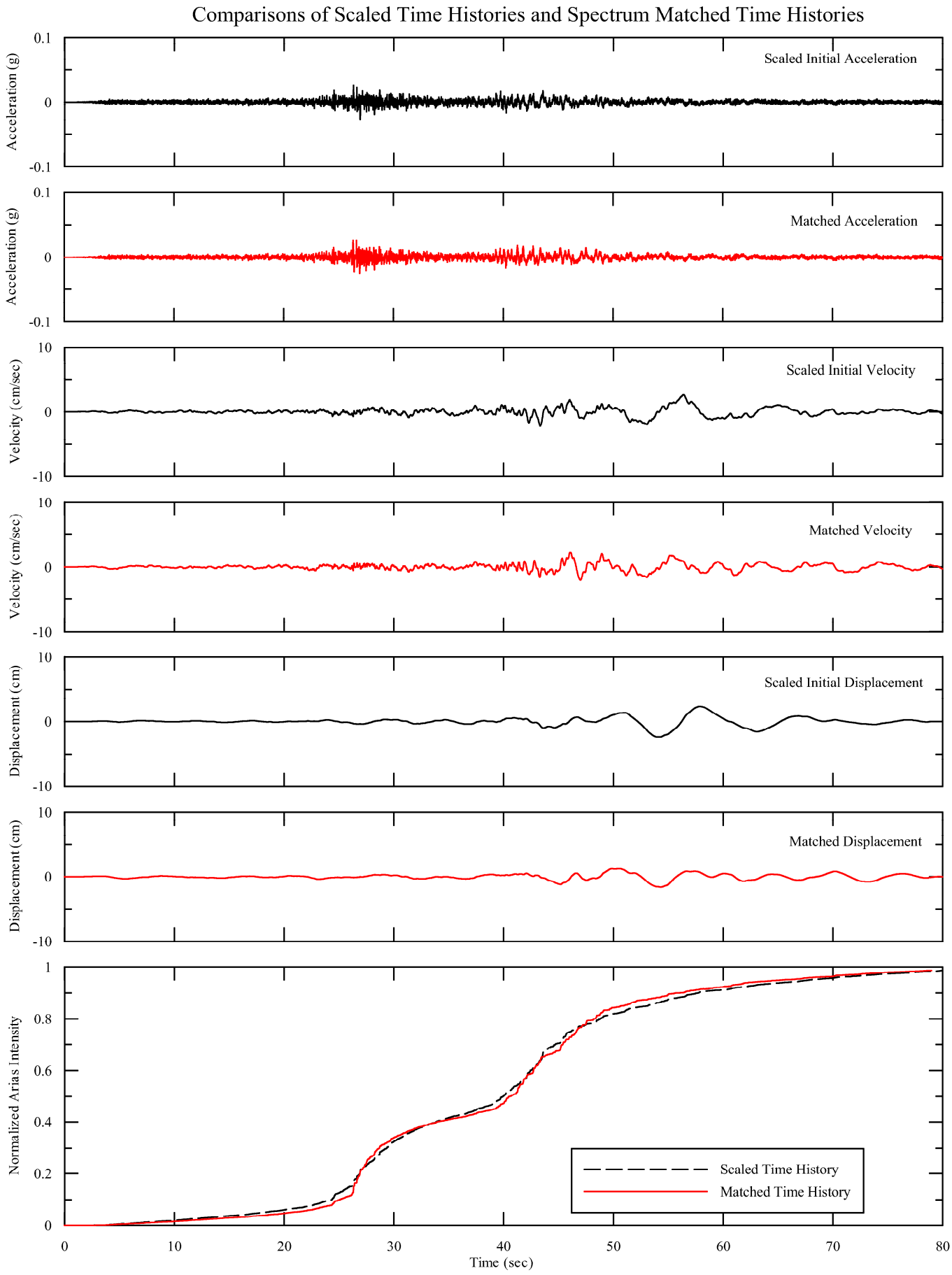


Seed Motion: 1999 Chi-Chi Earthquake, TAP075-W Station,
Match to Horizontal Target Spectrum

AMEC Geomatrix

Figure 69

I:\Project\13000\13452.003\12000 CALCS EVALS ANALYSIS\Kingston\Figures\TAP075-W_3_final.grf

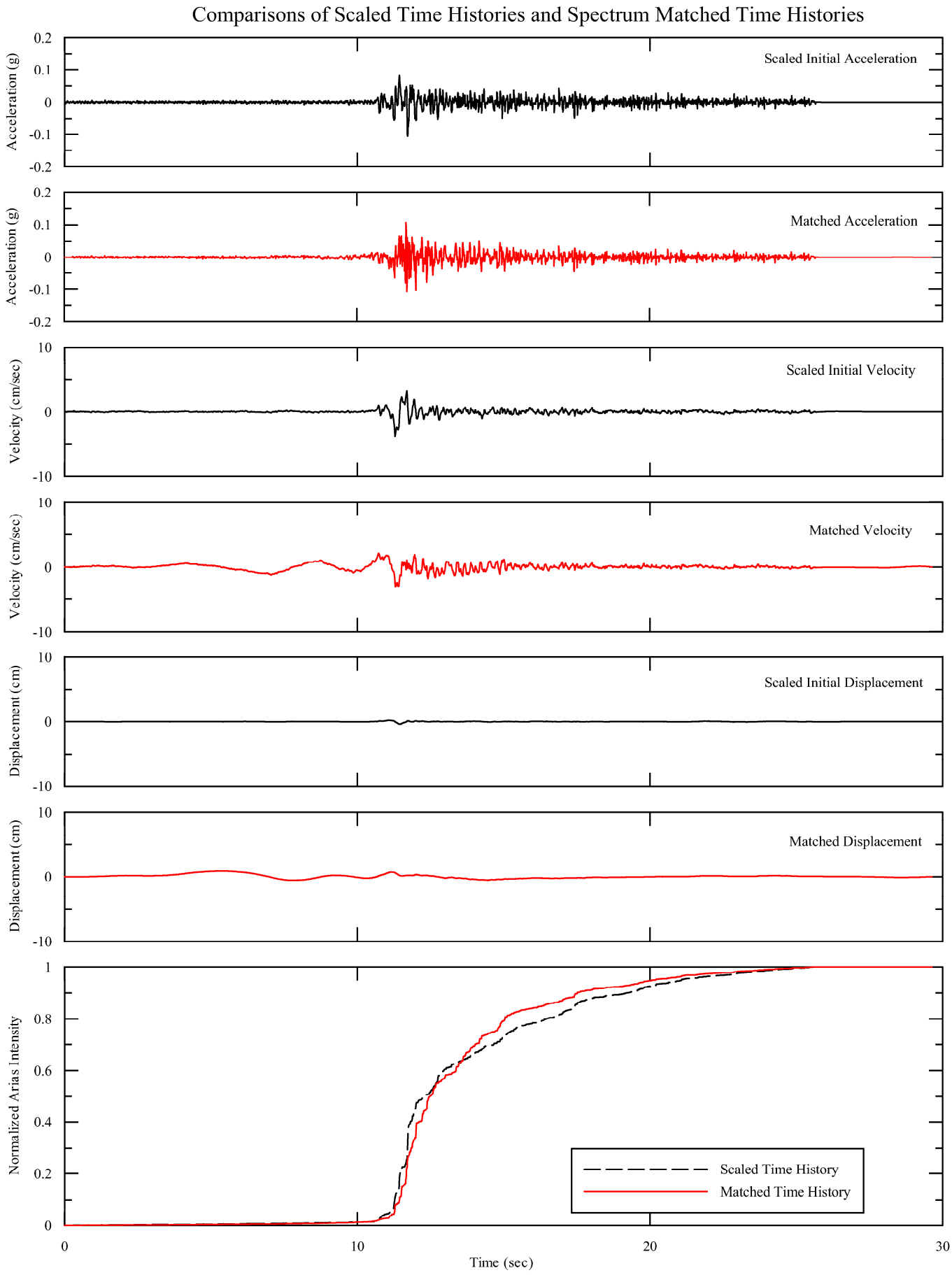


Seed Motion: 1999 Chi-Chi Earthquake, TAP075-V Station,
Match to Vertical Target Spectrum

AMEC Geomatrix

Figure 70

I:\Project\13000\13452.003\12000 CALCS EVALS ANALYSIS\Kingston\Figures\TAP075-V_3_final.grf

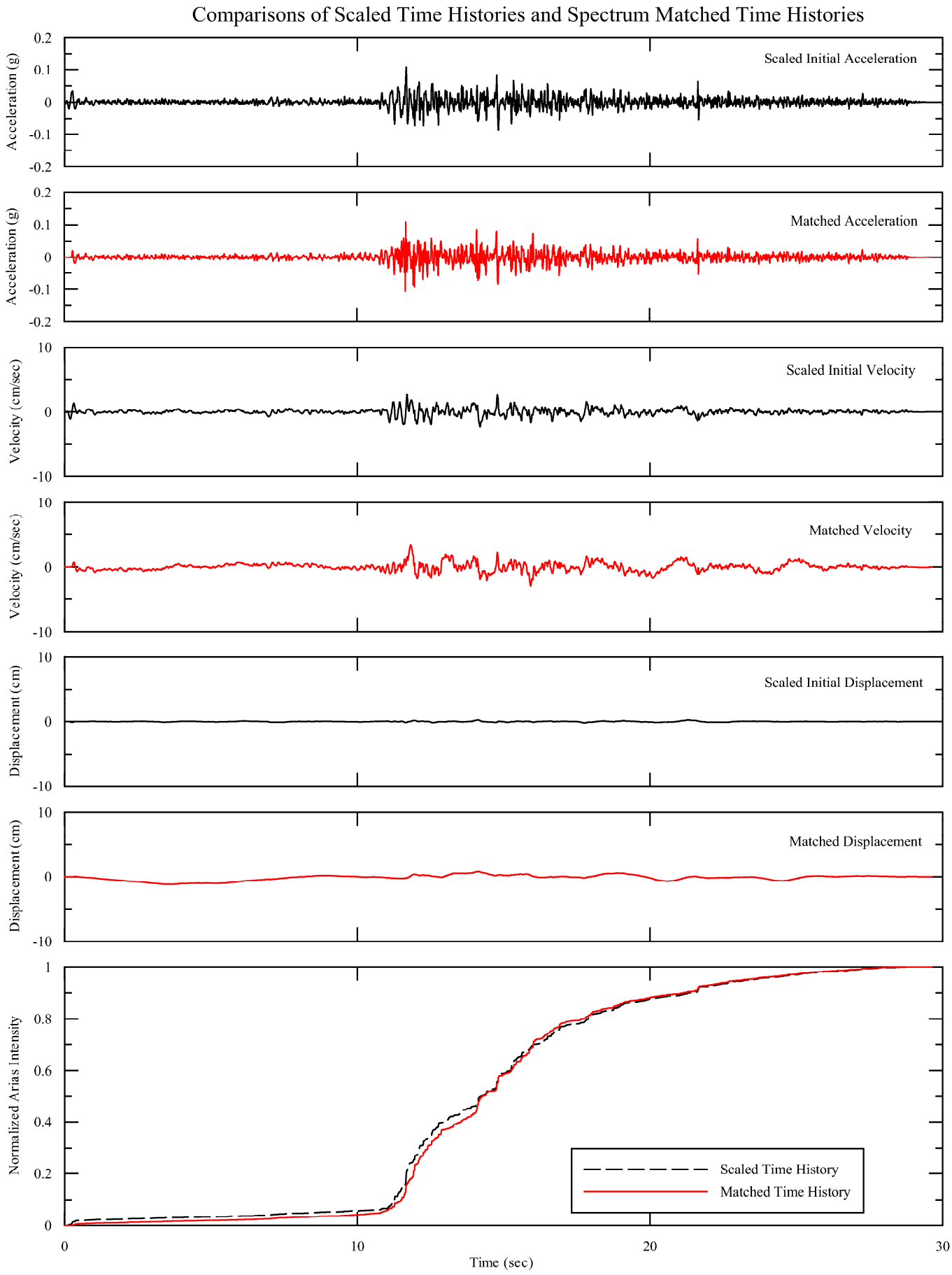


Seed Motion: 1988 Saguenay Earthquake, 1125S08L Station,
Match to Horizontal Target Spectrum

AMEC Geomatrix

Figure 71

I:\Project\13000\13452.003\12000 CALCS EVALS ANALYSIS\Kingston\Figures\SAG-L_3_final.grf

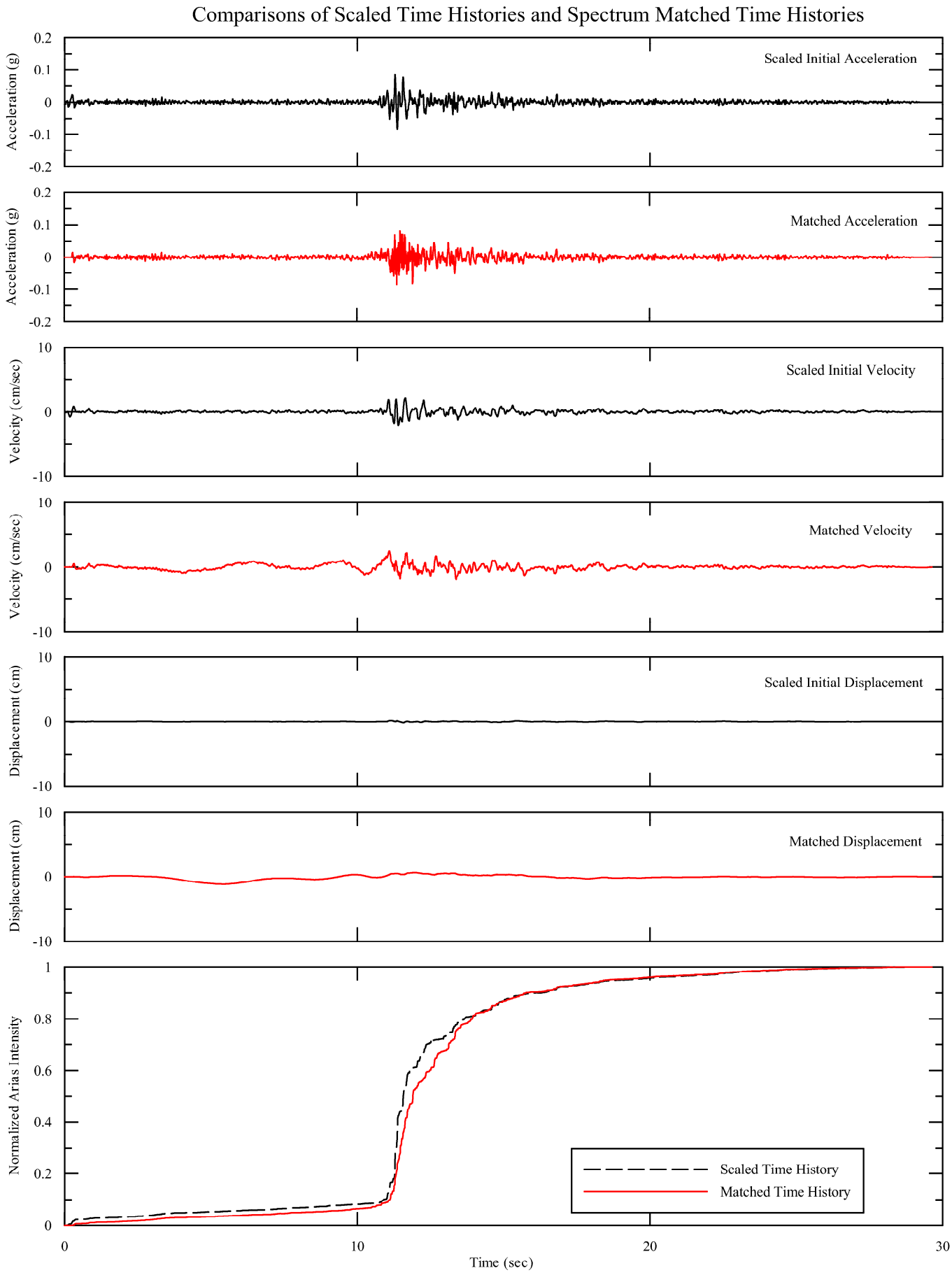


Seed Motion: 1988 Saguenay Earthquake, 1125S08T Station,
Match to Horizontal Target Spectrum

AMEC Geomatrix

Figure 72

I:\Project\13000\13452.003\12000 CALCS EVALS ANALYSIS\Kingston\Figures\SAG-T_3_final.grf

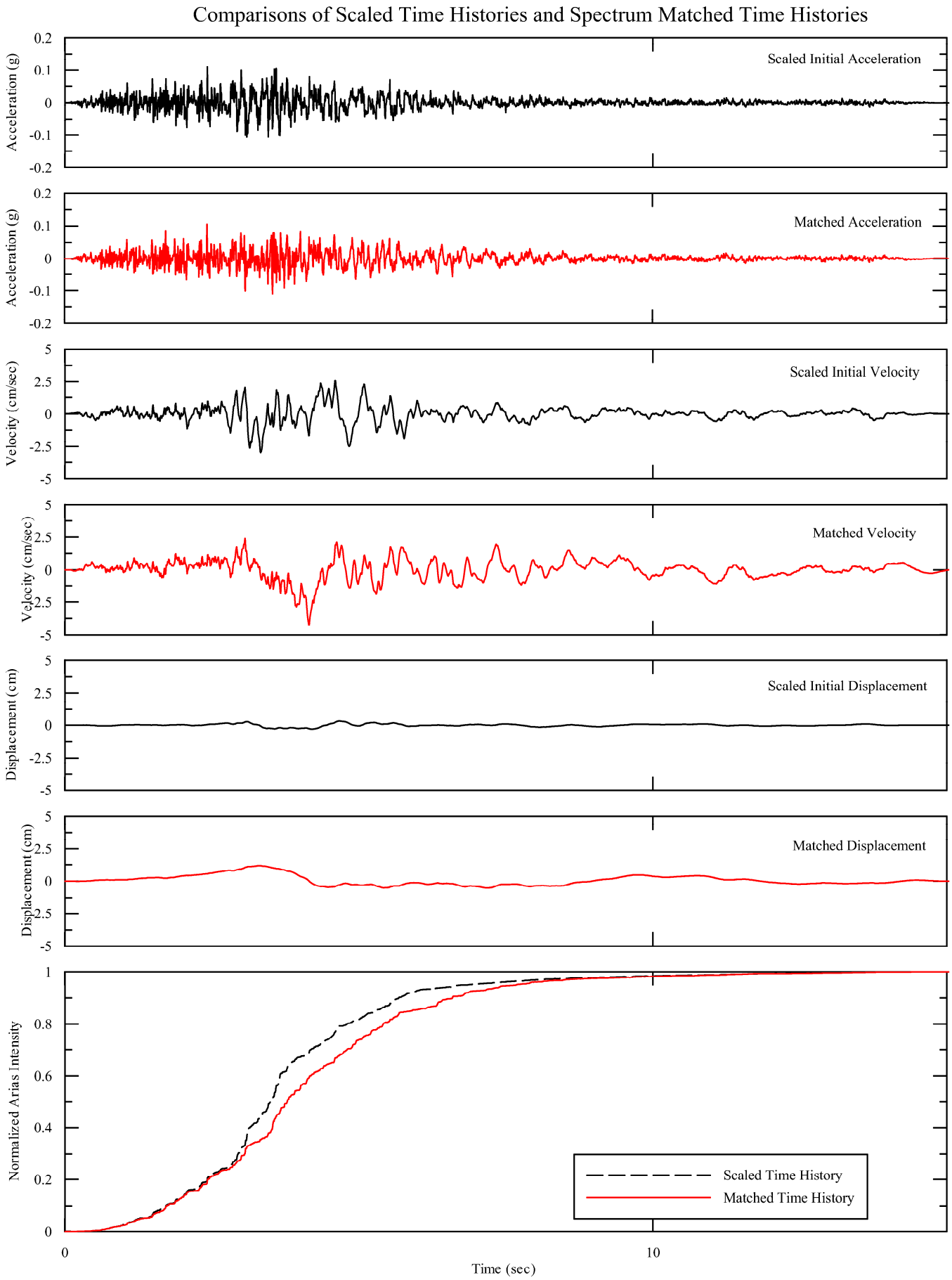


Seed Motion: 1988 Saguenay Earthquake, 1125S08V Station,
Match to Vertical Target Spectrum

AMEC Geomatrix

Figure 73

I:\Project\13000\13452.003\12000 CALCS EVALS ANALYSIS\Kingston\Figures\SAG-V_3_final.grf

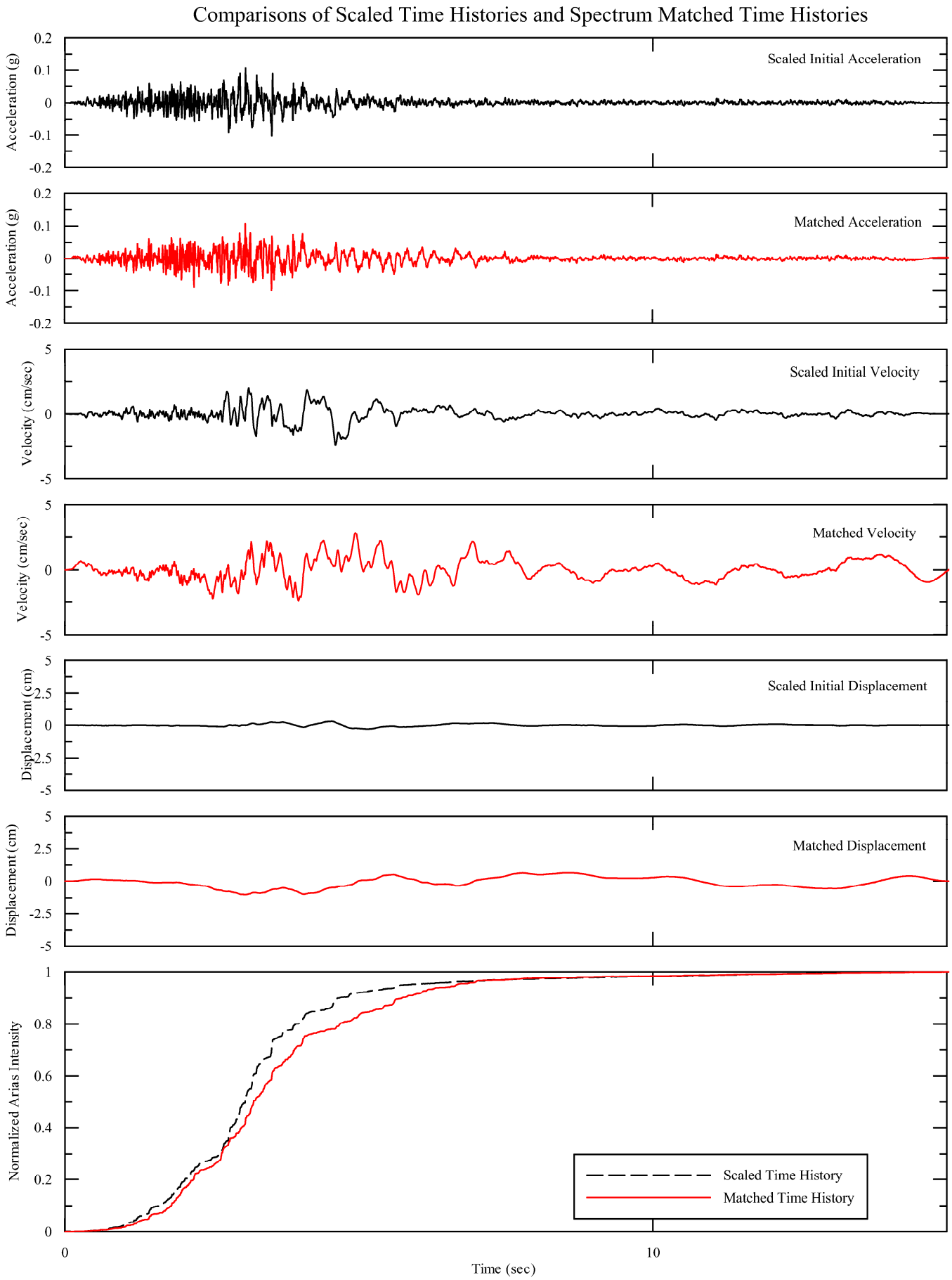


Seed Motion: 1987 Whittier Narrows Earthquake, A-GRV060 Station, Match to Horizontal Target Spectrum

AMEC Geomatrix

Figure 74

I:\Project\13000\13452.003\12000 CALCS EVALS ANALYSIS\Kingston\Figures\A-GRV060_3_final.grf

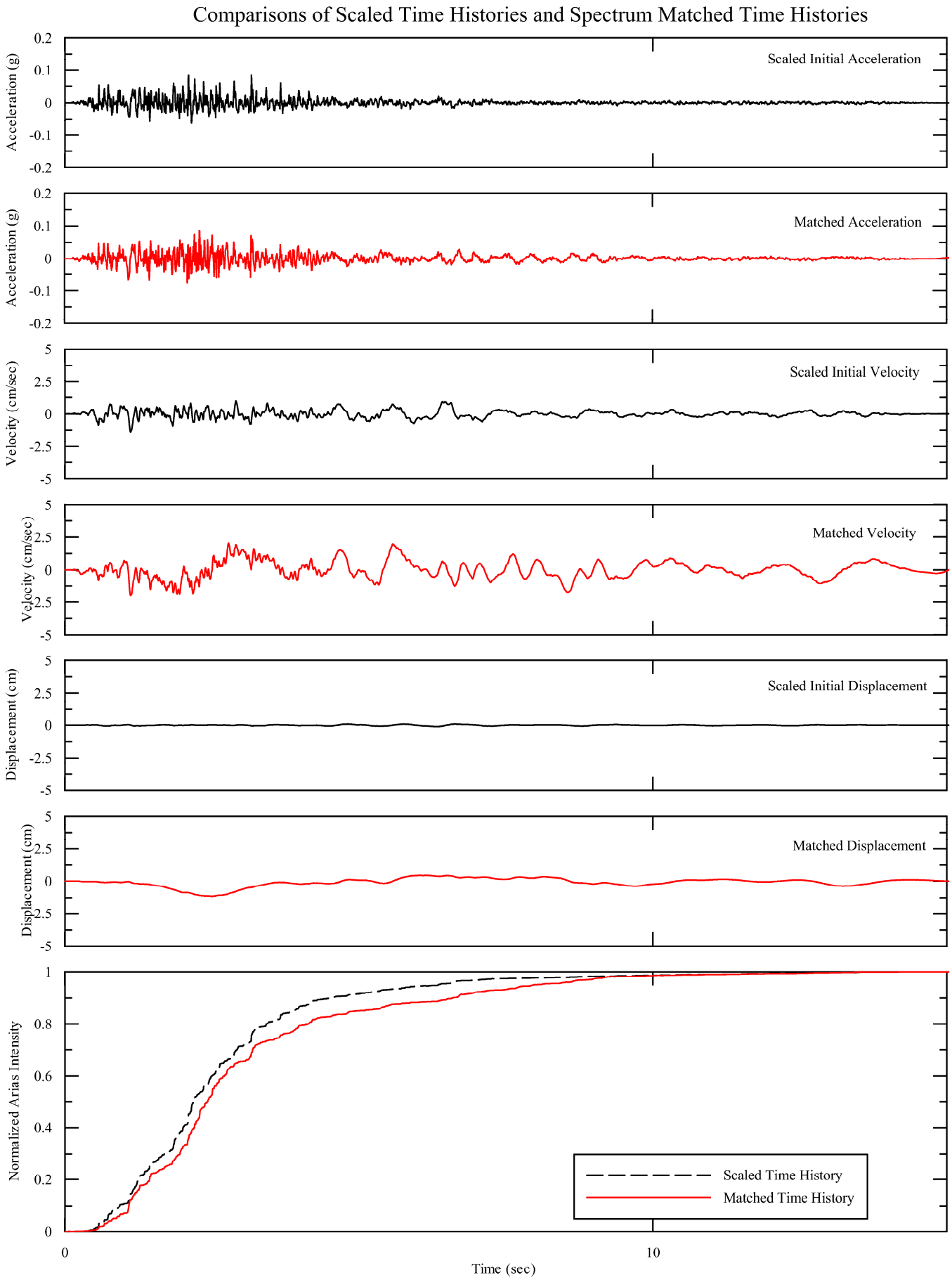


Seed Motion: 1987 Whittier Narrows Earthquake, A-GRV330 Station, Match to Horizontal Target Spectrum

AMEC Geomatrix

Figure 75

I:\Project\13000\13452.003\12000 CALCS EVALS ANALYSIS\Kingston\Figures\A-GRV330_3_final.grf

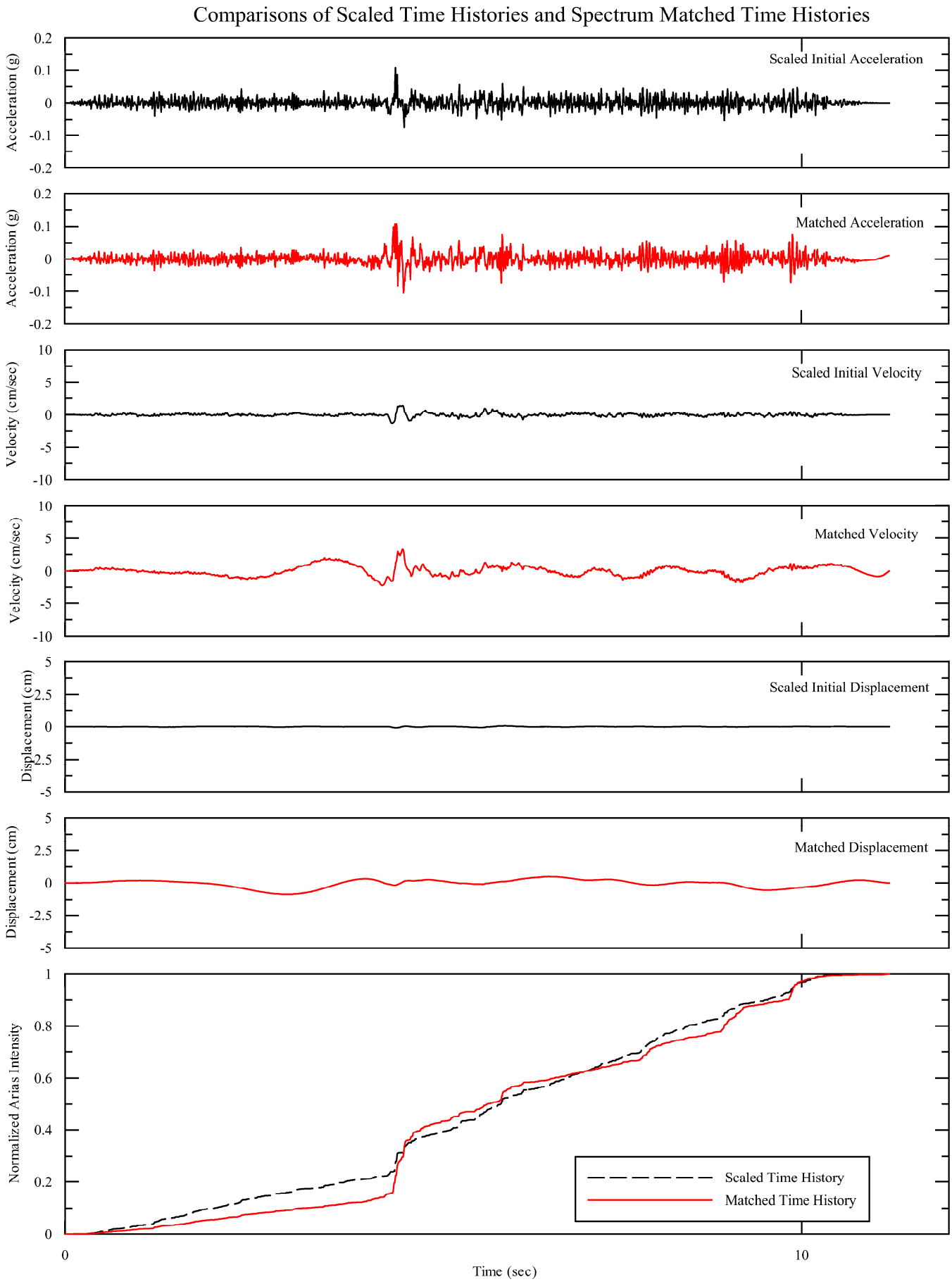


Seed Motion: 1987 Whittier Narrows Earthquake, A-GRV-UP Station, Match to Vertical Target Spectrum

AMEC Geomatrix

Figure 76

I:\Project\13000\13452.003\12000 CALCS EVALS ANALYSIS\Kingston\Figures\A-GRV-UP_3_final.grf

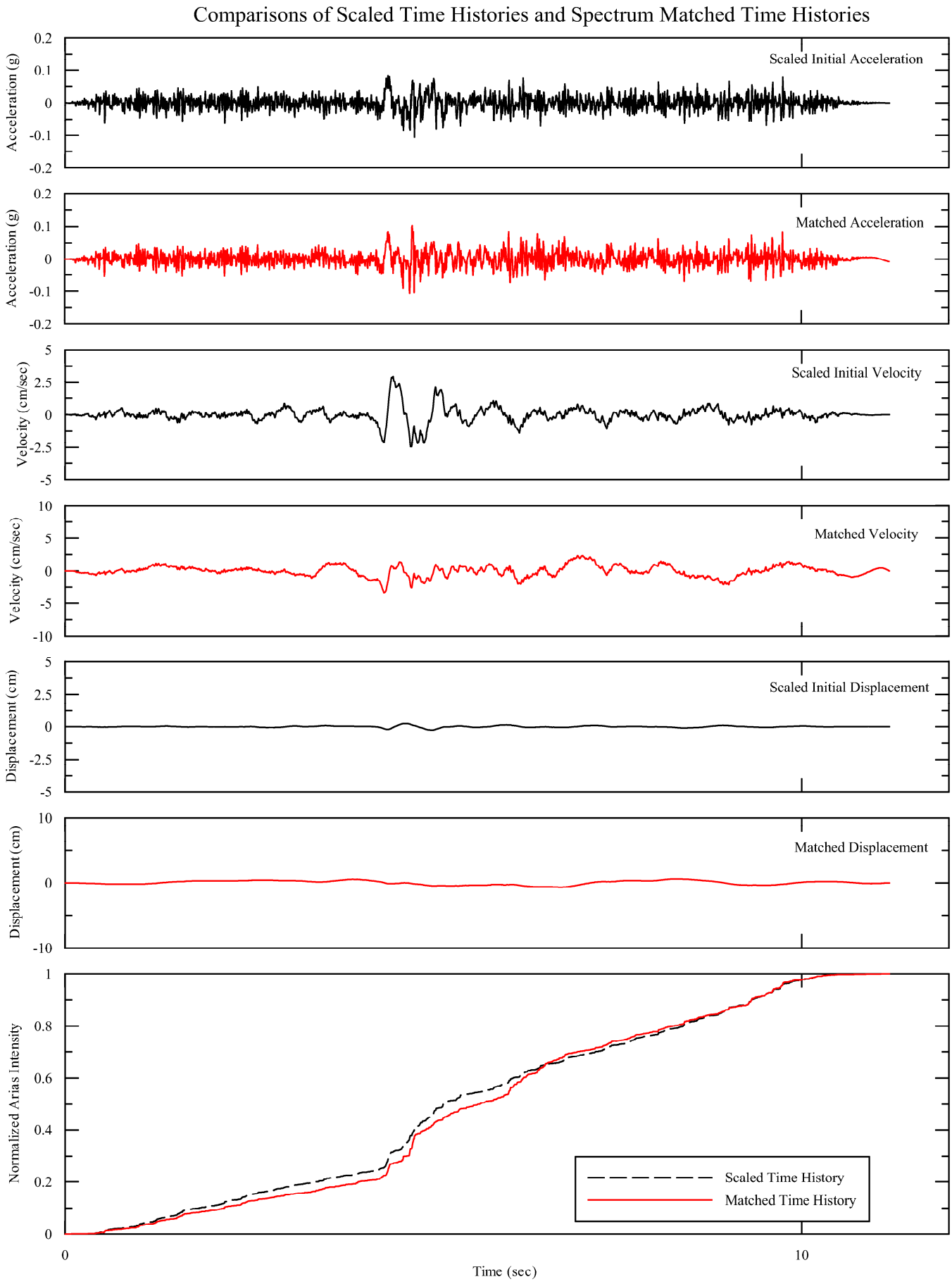


Seed Motion: 1986 N. Palm Springs Earthquake, HCP045 Station, Match to Horizontal Target Spectrum

AMEC Geomatrix

Figure 77

I:\Project\13000\13452.003\12000 CALCS EVALS ANALYSIS\Kingston\Figures\HCP045_3_final.grf

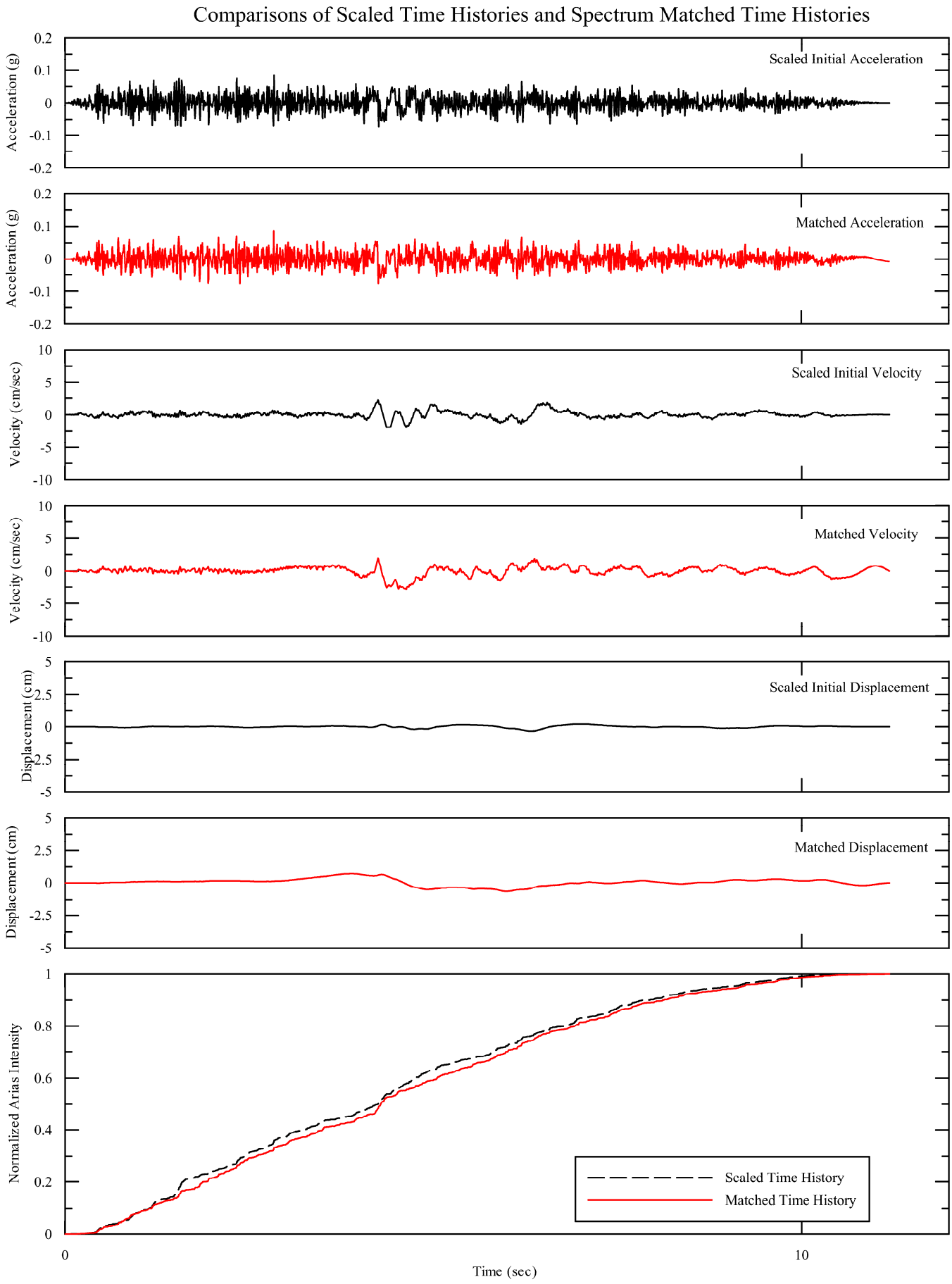


Seed Motion: 1986 N. Palm Springs Earthquake, HCP135 Station, Match to Horizontal Target Spectrum

AMEC Geomatrix

Figure 78

I:\Project\13000\13452.003\12000 CALCS EVALS ANALYSIS\Kingston\Figures\HCP135_3_final.grf



Seed Motion: 1986 N. Palm Springs Earthquake, HCP-UP Station, Match to Vertical Target Spectrum

AMEC Geomatrix

Figure 79

I:\Project\13000\13452.003\12000 CALCS EVALS ANALYSIS\Kingston\Figures\HCP-UP_3_final.grf