using PLAXIS 2D assuming plain strain conditions. However, due to the 3D nature of the excavation, we judged that a 3D analysis is more appropriate and thus presented in this memorandum.

Finite Element Model

Figure 2 shows the idealized 3D FE model and an east-west section of the Monument foundation and the surrounding Monument grounds. Fifteen node quadratic wedge elements were used to model both the subsurface soils and Monument foundation with finer elements in the vicinity of the Monument foundation. With the Monument at the center, the model extends approximately 1,000 ft wide, 1,000 ft long, and 118 ft deep to minimize boundary effects. Vertical boundaries were restrained along the horizontal normal to the boundary, while the bottom of the model was restrained in all directions (x, y, and z). The pyramidal Monument foundation is modeled explicitly using quadrilateral elements, while above ground portion of the Monument is represented as a distributed load acting on the top of the foundation based on the dead load provided by Silman Associates.

The uppermost fill varies in thickness from 12 ft to 25 ft forming a mound at the Monument. The ground surface elevations in the model generally follow the 2010 topographic survey. The underlying strata considered in our analysis were of uniform thickness consisting of 13.5 ft of Stratum T2/T1(A), 24 ft of Stratum T3, 40 ft of T1(D), and 15 ft of Stratum D. The groundwater table was conservatively taken to be at Elev.0. The Monument foundation is supported directly on Stratum T3 and is underlain by Strata T1(D) and D.

Material Properties

To describe the soil and rock behaviors, we used the linear elastic model for Strata F, T1(A)/T2, and D and the Monument foundation, and the Hardening Soil (HS) model for Strata T3 and T1(D). The HS model features a stress-dependent stiffness and an unload/reload response for more realistic estimates of Strata T3 and T1(D) material response. Tables 1 and 2 summarize the material properties assumed in our analysis. We selected the material properties based on the in-house and published geotechnical data, laboratory test results, and empirical correlations. Since most of the settlement/swelling response would come from Stratum T1(D), we calibrated our HS model using laboratory consolidation tests data. We first corrected the laboratory test data using the Schmertmann (1955) graphical procedure to account for sample disturbance. The corrected consolidation parameters (C_C and C_S) were then used to calibrate the Stratum T1(D) HS model in PLAXIS. Figure 3 shows the actual laboratory test data, Schmertmann corrected data, and calibrated PLAXIS HS model.

Initial Stresses and Calculation Phases

Phased analyses were performed to simulate an in-situ stress state of the FE model. Figure 4 shows the initial phase of our FE model which consists of Strata T2/T1(A), T3, T1(D), and D. The model was first brought to equilibrium under geostatic K_o conditions. To simulate the overconsolidated nature of Stratum T1(D), we applied a uniform aerial load of 7.5 ksf at the surface (see Figure 5) and then removed the load to simulate an OCR profile of 2 to 3 for Stratum T1(D) as measured in our previous subsurface investigation (see Figure 6).

The next several phases consisted of constructing and loading the original foundation (see Figure 7), underpinning of the original foundation (see Figure 8), building of the mound and increasing the load to the current level (see Figure 9). The calculation phases followed the actual sequence of the Monument as described in the previous section. Figure 10 shows the current in-situ vertical effective stress (σ'_v) used in our analysis (before excavation). To keep track of the induced deformations due to the proposed excavation, displacements were reset to zero prior to simulation of excavation.

Calculation Results

As the design is still in the conceptual stage, the depth and geometry for the excavation were approximated in this study. The excavated volume takes into account the net reduction of loads due to the excavated soil, the weight of the structure, and backfilled soil at the end of construction. Deformations such as heaving or settlement at the edges of the base of the Monument (see Figure 11) were monitored in the model and the differential settlement along the east-west direction of the Monument was calculated. Excavation was performed in stages, first excavating the tunnel, and then the recessed entry.

Figure 12 shows the excavation for the tunnel. Figure 13 shows the vertical displacements due to the excavation for the tunnel. Results of our analysis indicate that the edge of the monument foundation closest to the excavation (Point A) will heave on the order of 0.2 inch (upward) while the edge of the monument foundation furthest from the excavation (Point B) will have negligible movement. Differential settlement due to this stage of excavation along the base of the foundation is on the order of 0.01% (0.01/100).

Figure 14 shows the excavation for the tunnel and recessed entrance for Alternative A1. Figure 15 shows the vertical displacements due to the excavation for the tunnel and recessed entrance for the assumed soil profile. Results of our analysis indicate that the edge of the monument foundation closest to the excavation (Point A) will heave on the order of 0.4 inch (upward) while the edge of the monument foundation furthest from the excavation (Point B) will settle on the order of 0.1 inch (downward). Differential settlement along the base of the foundation is on the order of 0.03% (0.03/100). We expect 90% of the movements to occur during the relatively short duration of construction.

We note that the settlement and heave estimates are based upon a uniform subsurface profile, average soil parameters obtained from a limited number of laboratory tests, and an excavation geometry based on a conceptual scheme. We recommend that the settlement and heave estimates be revised once the final scheme is selected and that parametric studies be performed to determine sensitivity to soil parameters and stratification.

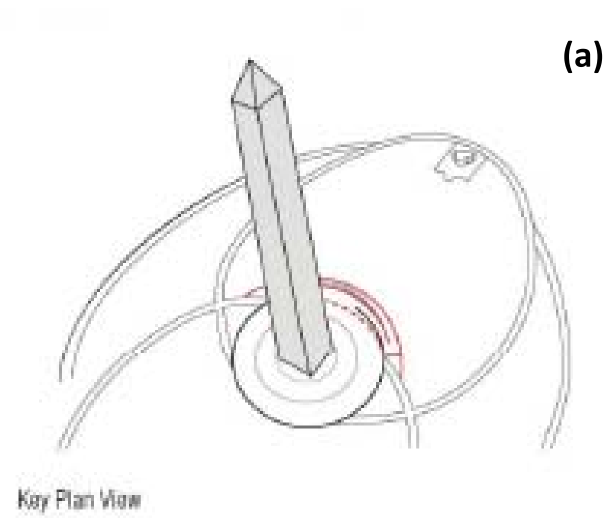


Figure 1. a) Conceptual drawing of Alternative A1 by BBB
b) Cross section along direction of ramps.

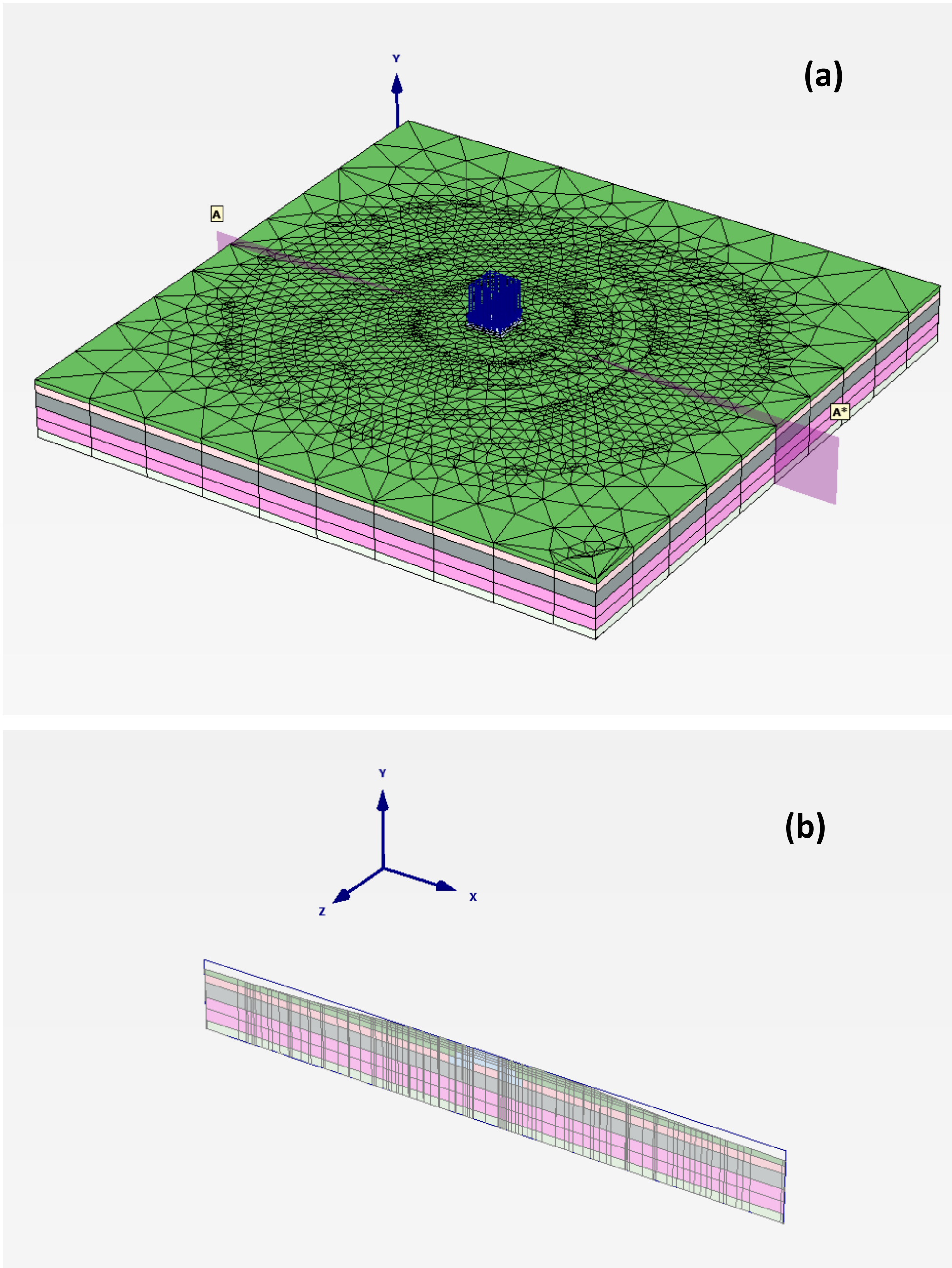


Figure 2. Finite Element Model: a) 3D Model, b) section along east-west direction.

Table 1. Summary of Linear Elastic Material Properties – Strata F, T2, D, and Monument Foundation.

Stratum	γ (lb/ft^3)	ν	E (ksf)
Fill	130	0.30	380
Stratum T2	130	0.30	515
Stratum D	150	0.20	60,000
Masonry	150	0.20	570,000

γ: Unit weight
ν: Poisson's Ratio
E: Young's Modulus

Table 2. Summary of Hardening Soil Material Properties – Strata T1(D) and T3.

Stratum	γ (lb/ft^3)	E_{50ref} (ksf)	E_{oedref} (ksf)	E_{urref} (ksf)	c' (ksf)	ϕ (°)	ψ (°)	ν_{ur}	power (m)
Stratum T1(D)	130	18	15	62	0	28	0	0.20	1.0
Stratum T3	130	550	370	1,650	0	36	0	0.20	0.5

γ: Unit weight
ν_{ur}: Poisson's Ratio
E_{50ref}, E_{oedref}, E_{urref}, m: PLAXIS HS Parameters
c': Effective cohesion
ϕ: Effective friction angle

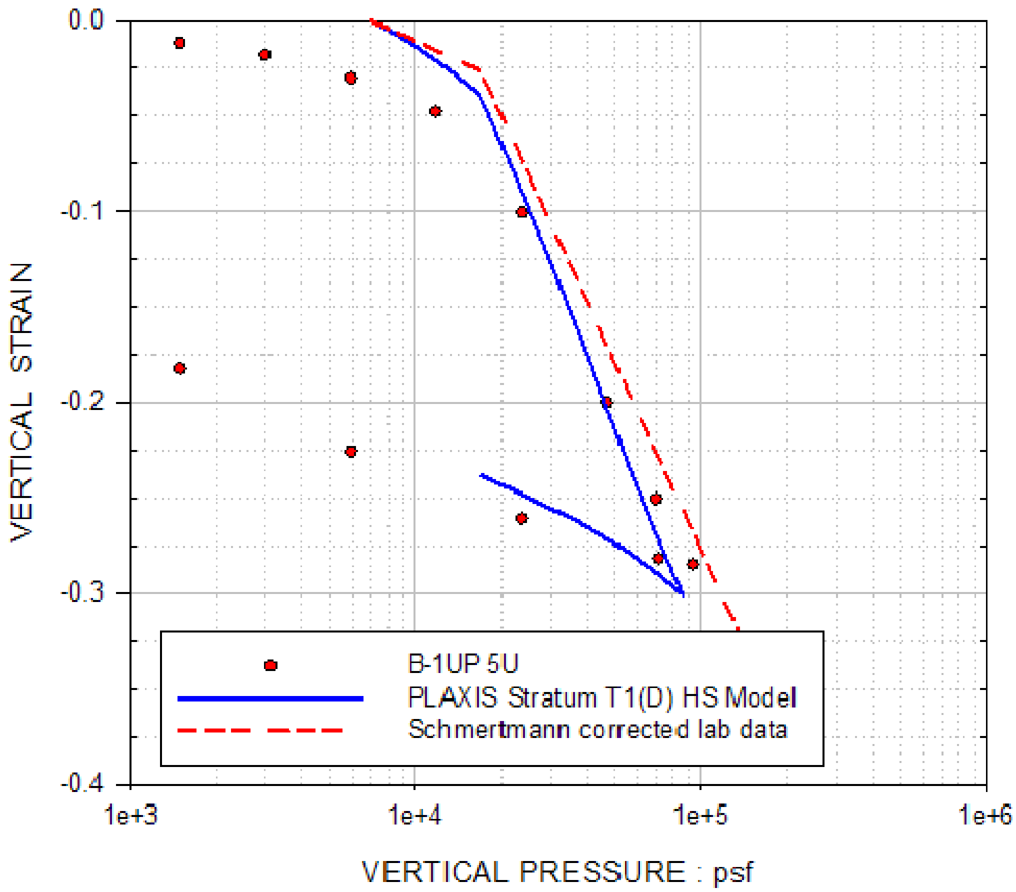


Figure 3. Calibration of PLAXIS Stratum T1(D) HS model.

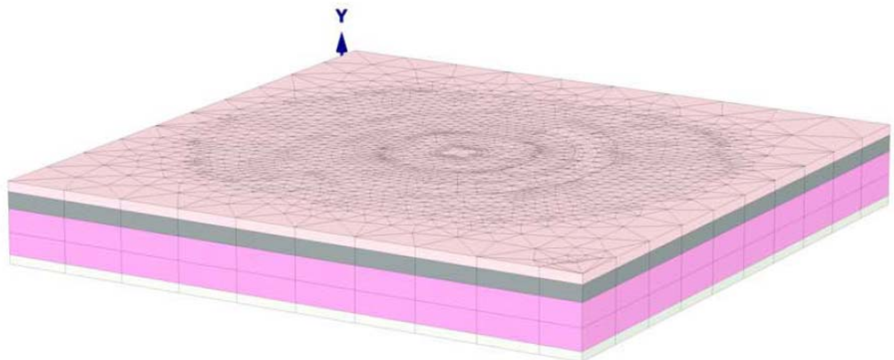


Figure 4. Initial FE Model

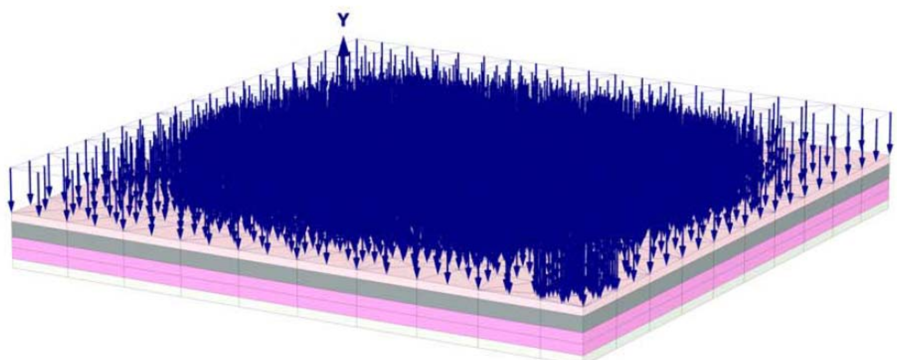


Figure 5. 7.5 ksf initial load.

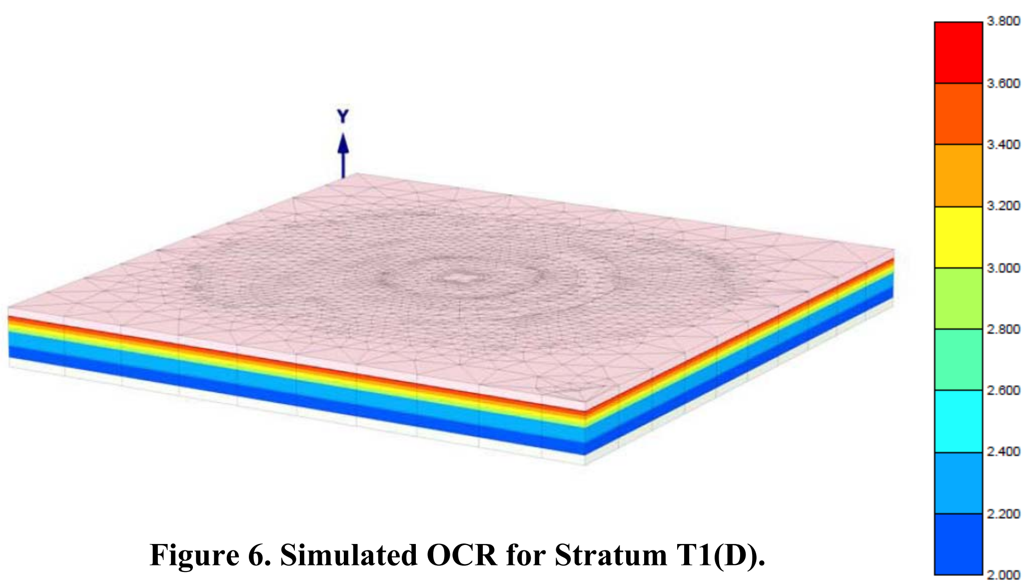


Figure 6. Simulated OCR for Stratum T1(D).

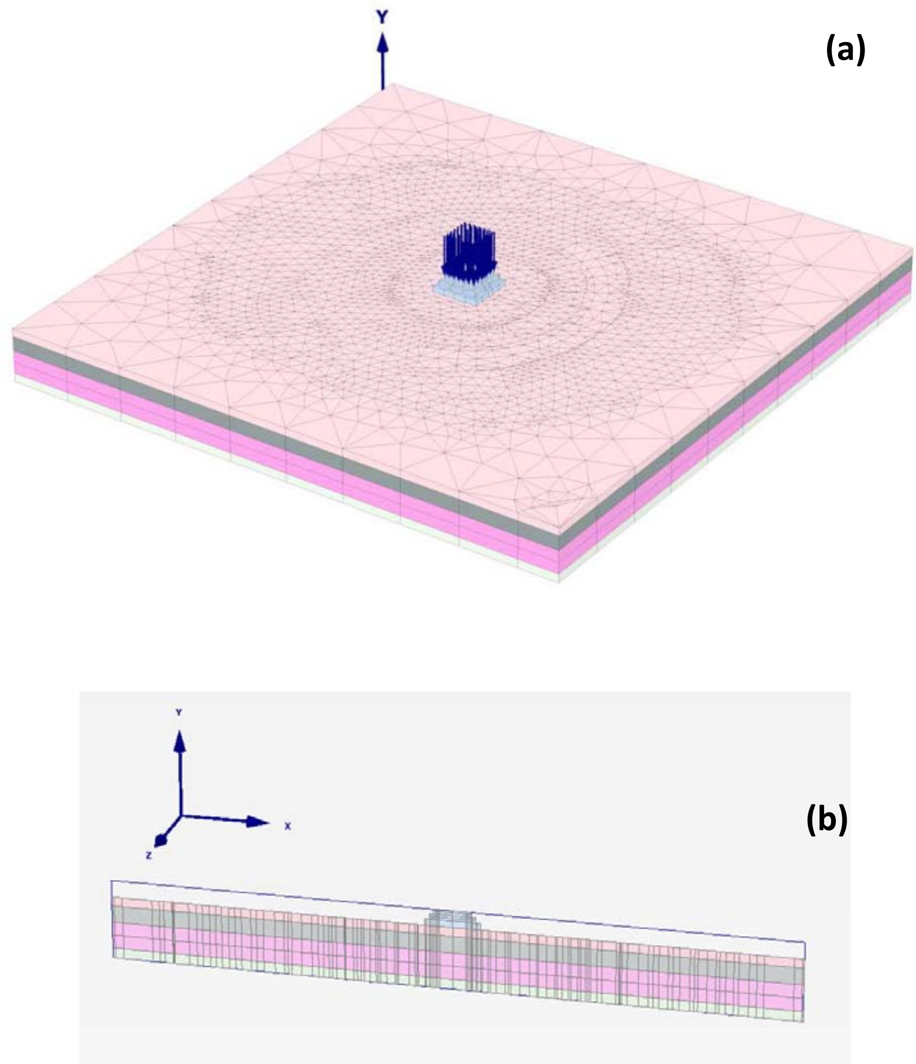
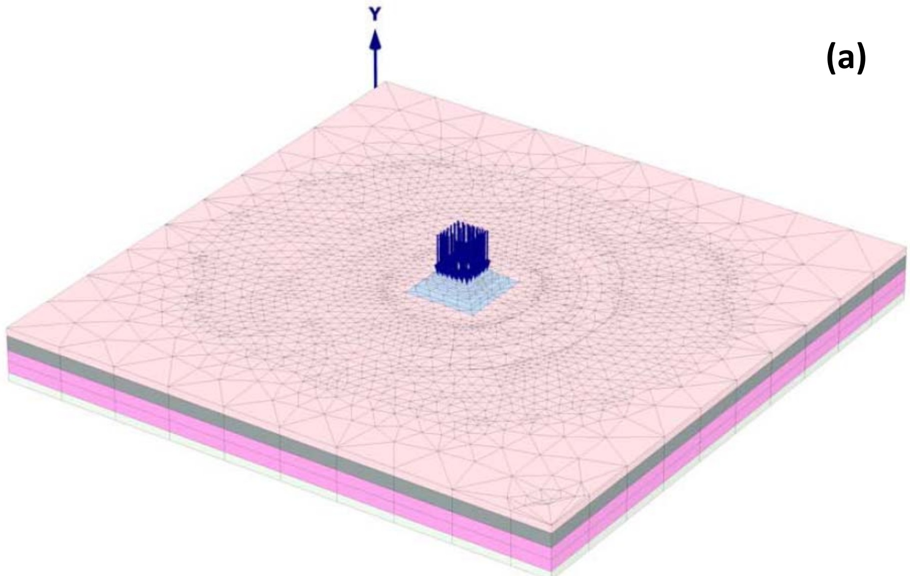


Figure 7. Construct original foundation: a) 3D view; b) section along east-west of Monument.



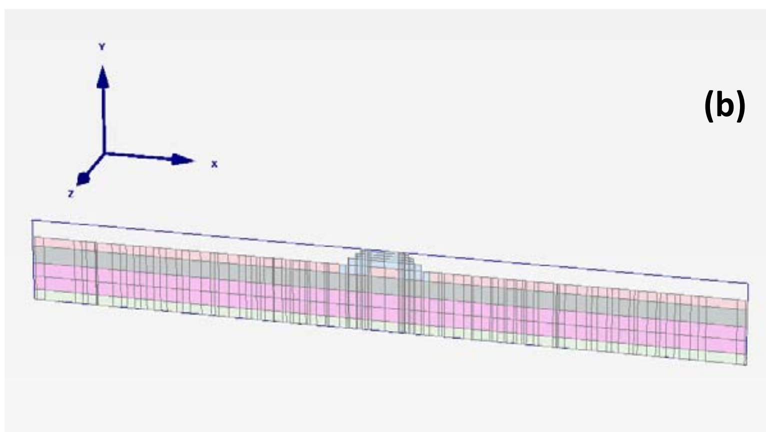


Figure 8. Underpinning of Monument foundation: a) 3D view; b) section along east-west of Monument.

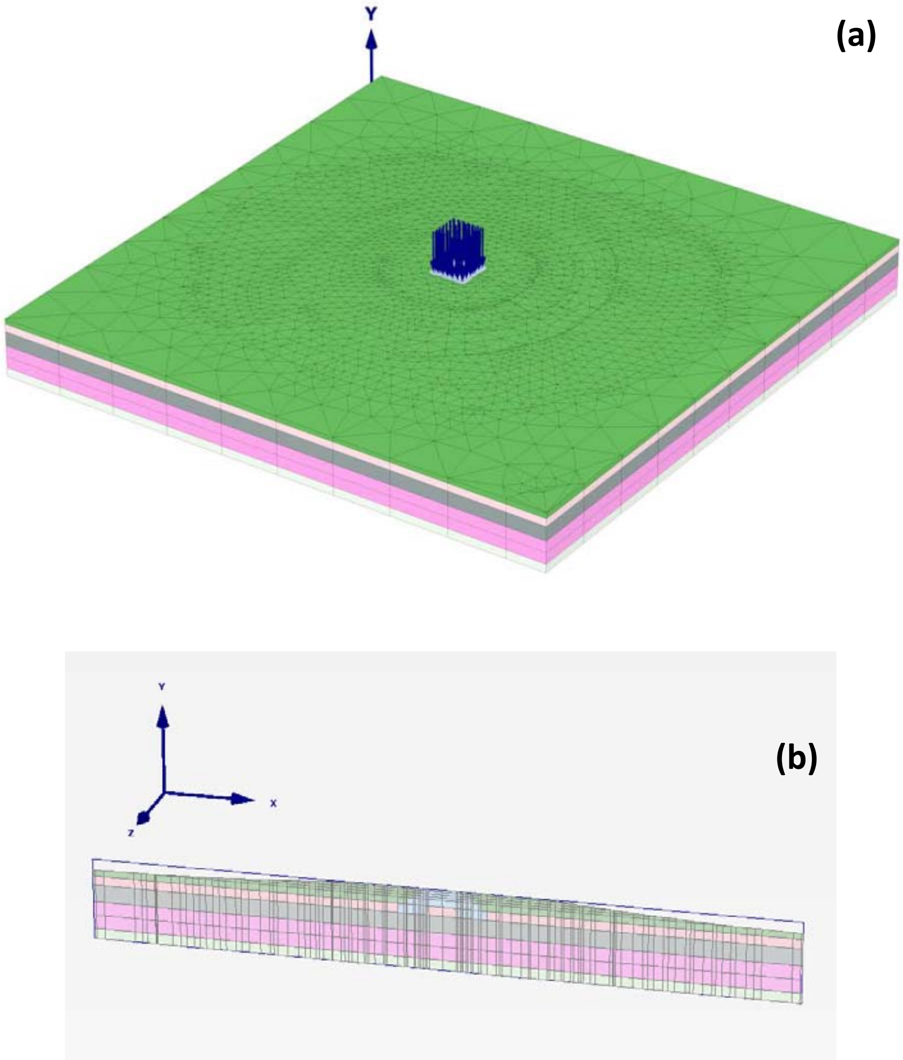


Figure 9. Construction of mound: a) 3D view; b) section along east-west of Monument.

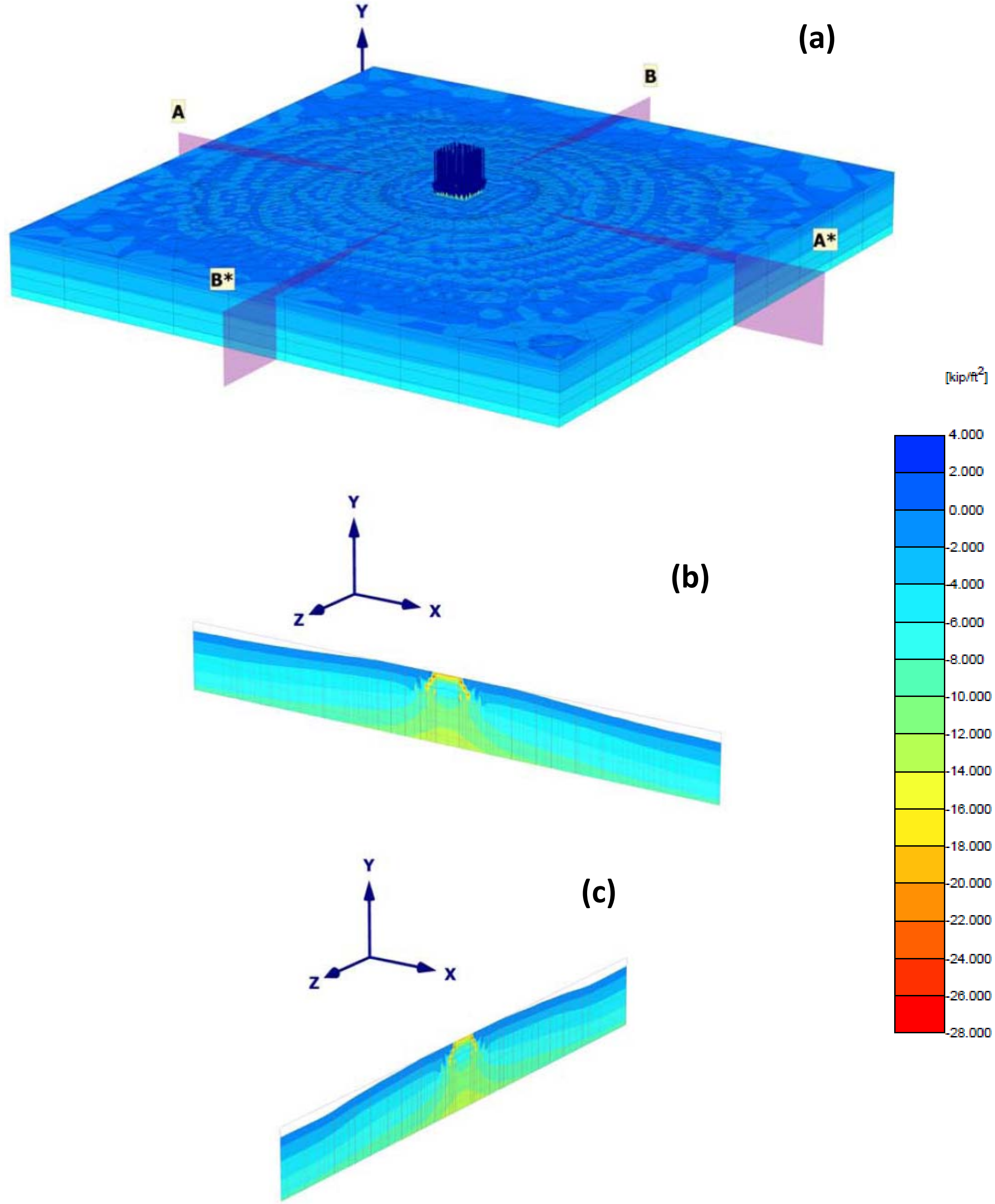


Figure 10. In-situ vertical effective stress: a) 3D model; b) Section A-A*; c) Section B-B*.

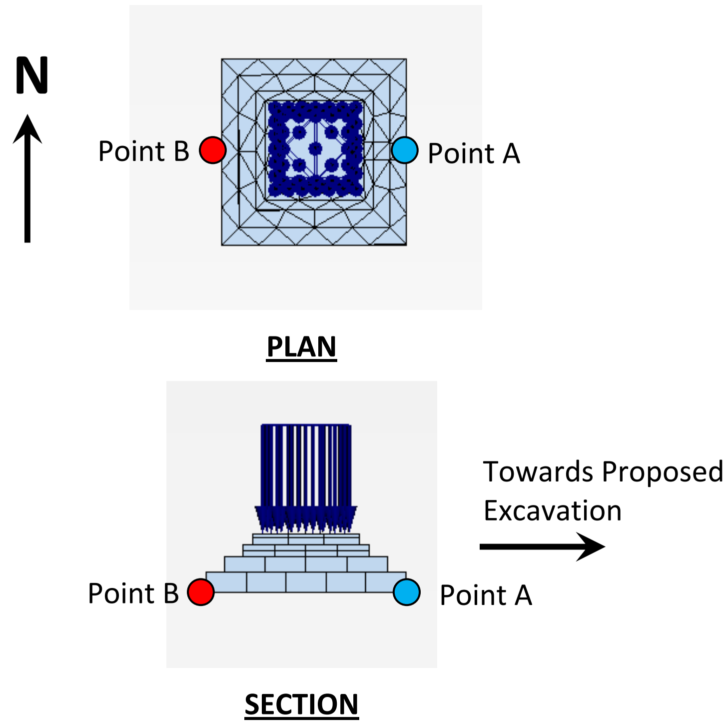


Figure 11. Points monitored during excavation

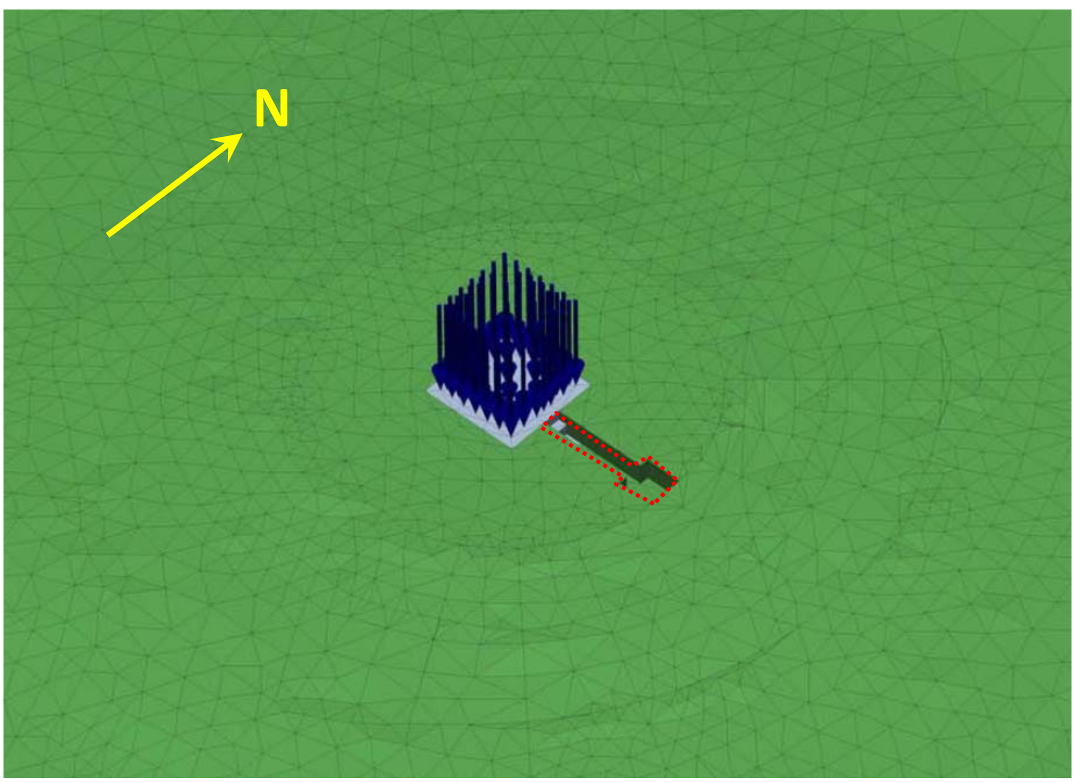


Figure 12. Excavation for Alternative A1: tunnel.

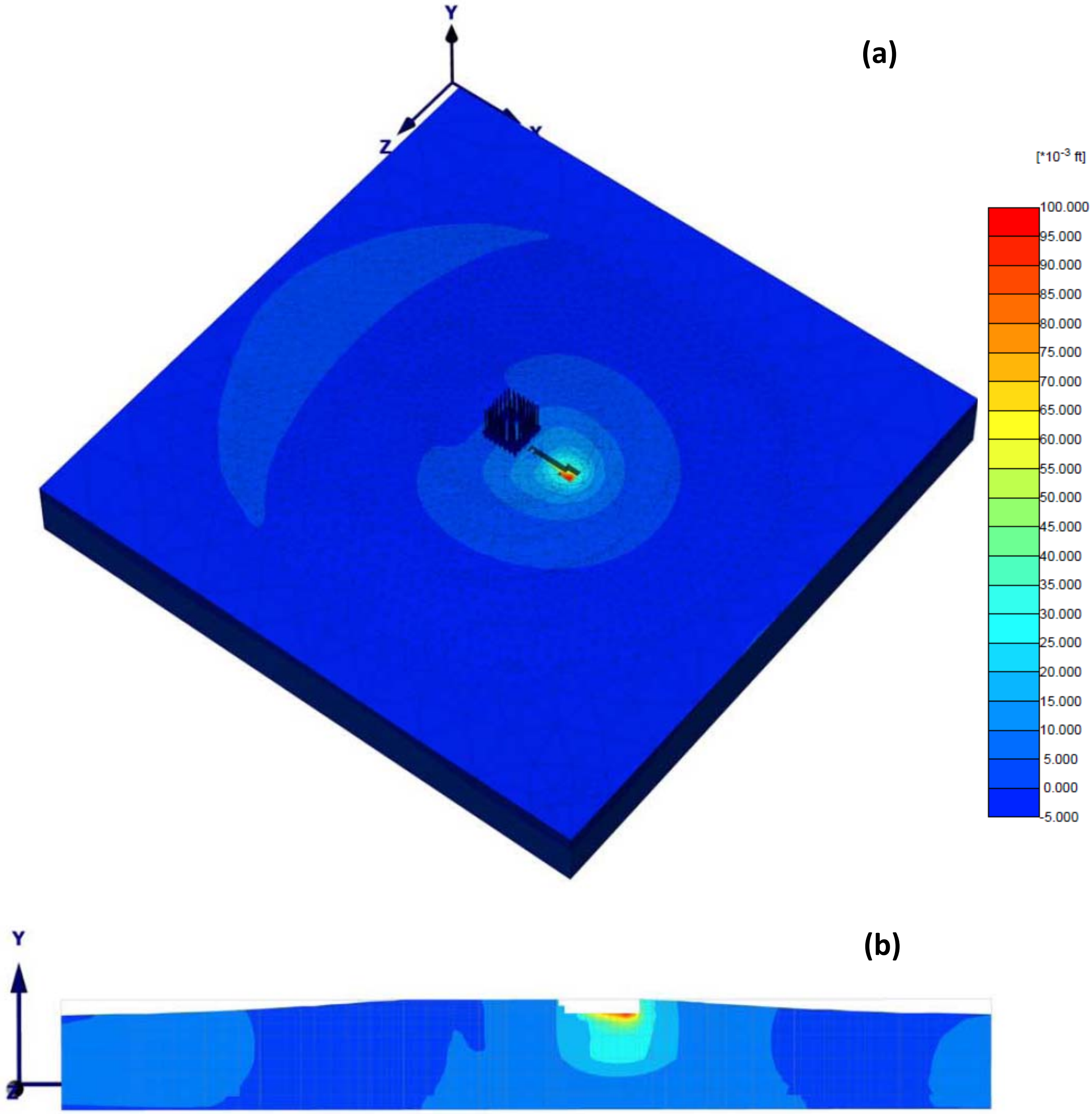


Figure 13. Vertical displacements due to tunnel excavation: a) 3D view; b) section along east-west of Monument.

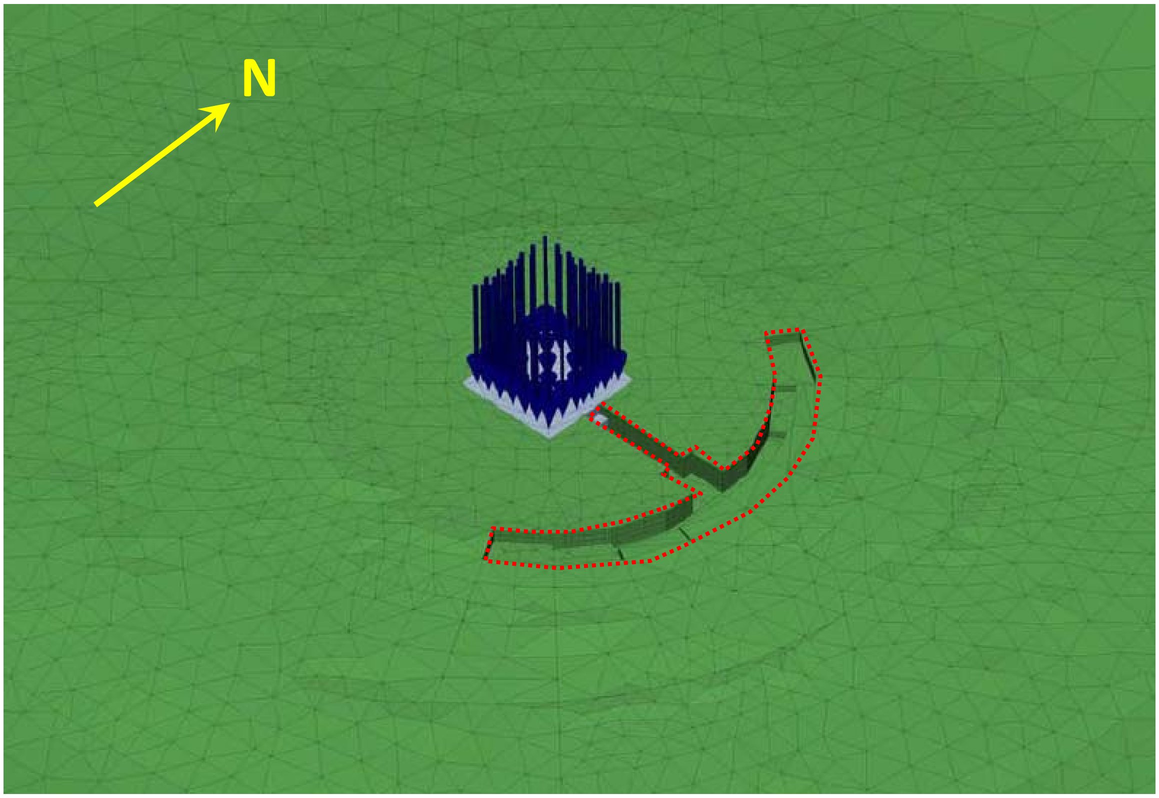


Figure 14. Excavation for Alternative A1: tunnel and recessed entrance.

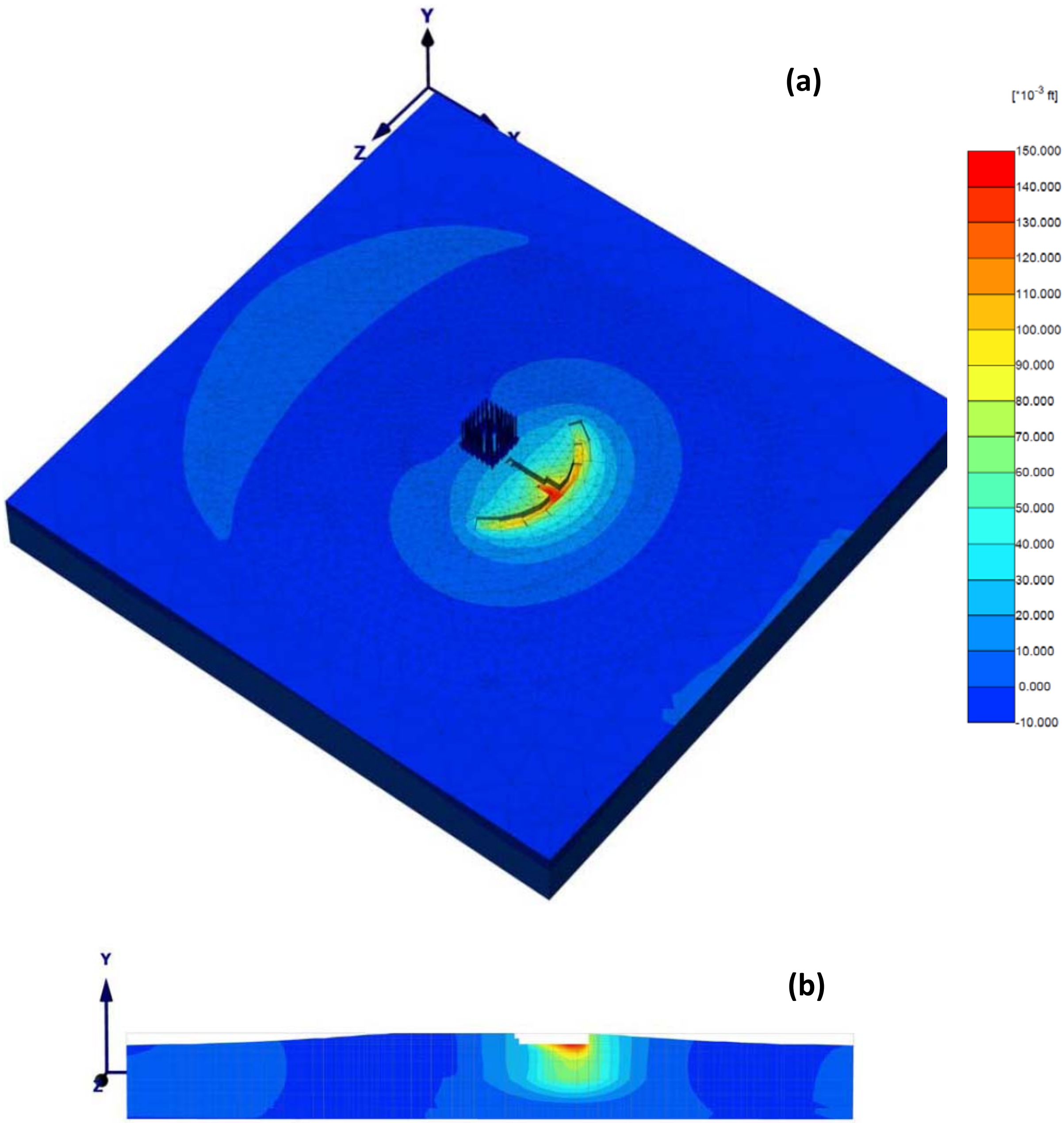


Figure 15. Vertical displacements due to tunnel and recessed entrance excavation: a) 3D view; b) section along east-west of Monument.

APPENDIX B

Modified Mercalli Intensity Scale

APPENDIX B

MODIFIED MERCALLI INTENSITY SCALE

Washington Monument
Washington, District of Columbia

Introductory text is abridged from *The Severity of an Earthquake*, a U. S. Geological Survey General Interest Publication. U.S. Government Printing Office: 1989-288-913

The effect of an earthquake on the Earth's surface is called the intensity. The intensity scale consists of a series of certain key responses such as people awakening, movement of furniture, damage to chimneys, and finally - total destruction. Although numerous *intensity scales* have been developed over the last several hundred years to evaluate the effects of earthquakes, the one currently used in the United States is the Modified Mercalli (MM) Intensity Scale. It was developed in 1931 by the American seismologists Harry Wood and Frank Neumann. This scale, composed of 12 increasing levels of intensity that range from imperceptible shaking to catastrophic destruction, is designated by Roman numerals. It does not have a mathematical basis; instead it is an arbitrary ranking based on observed effects.

The Modified Mercalli Intensity value assigned to a specific site after an earthquake has a more meaningful measure of severity to the nonscientist than the magnitude because intensity refers to the effects actually experienced at that place. After the occurrence of widely-felt earthquakes, the Geological Survey mails questionnaires to postmasters in the disturbed area requesting the information so that intensity values can be assigned. The results of this postal canvass and information furnished by other sources are used to assign an intensity within the felt area. The maximum observed intensity generally occurs near the epicenter.

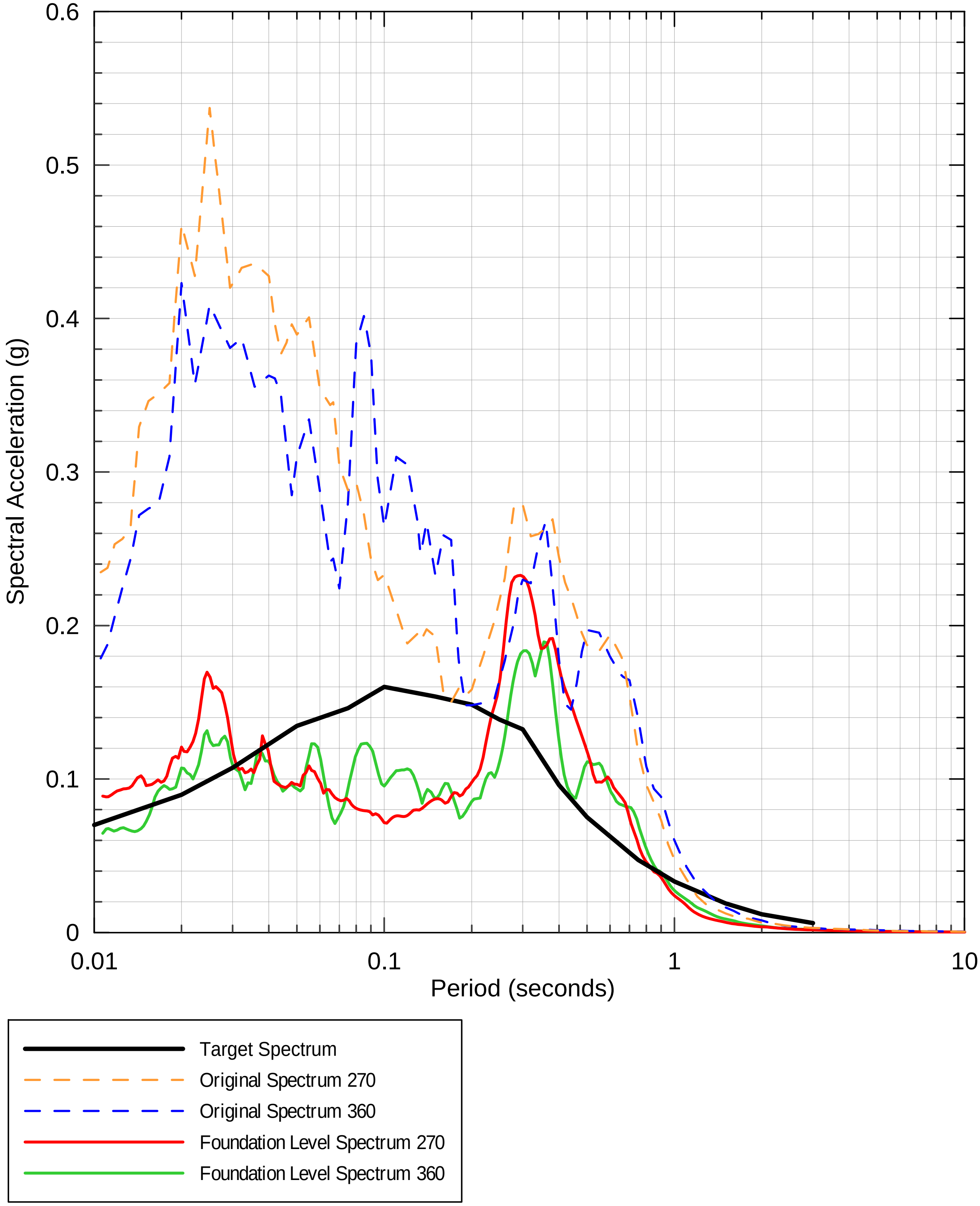
The *lower* numbers of the intensity scale generally deal with the manner in which the earthquake is felt by people. The *higher* numbers of the scale are based on observed structural damage. Structural engineers usually contribute information for assigning intensity values of VIII or above.

The following is a description of the 12 levels of Modified Mercalli intensity adapted from Bruce A. Bolt, Abridged Modified Mercalli Intensity Scale, *Earthquakes 2006 Centennial Update*, Appendix C, W.H. Freeman and Co. 2006, 338 pp.

Intensity Value	Description
I	Not felt except by a very few under especially favorable circumstances. (I Rossi-Forel scale)
II	Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing. (I to II Rossi-Forel scale)
III	Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing automobiles may rock slightly. Vibration like passing of truck. Duration estimated. (III Rossi-Forel scale)
IV	During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls make creaking sound. Sensation like heavy truck striking building. Standing automobiles rocked noticeably. (IV to V Rossi-Forel scale)
V	Felt by nearly everyone, many awakened. Some dishes, windows, and so on broken; cracked plaster in a few places; unstable objects overturned. Disturbances of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop. (V to VI Rossi-Forel scale)
VI	Felt by all, many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster and damaged chimneys. Damage slight. (VI to VII Rossi-Forel scale)
VII	Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving cars. (VIII Rossi-Forel scale)
VIII	Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stack, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving cars disturbed. (VIII + to IX Rossi-Forel scale)
IX	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken. (IX + Rossi-Forel scale)
X	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed, slopped over banks. (X Rossi-Forel scale)
XI	Few, if any, (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.
XII	Damage total. Waves seen on ground surface. Lines of sight and level distorted. Objects thrown into the air.

APPENDIX C

Plots of Response Spectra and Original and Scaled Time Histories



Horizontal Response Spectra
1986, N. Palm Springs, Anza - Tule Canyon
Foundation Level Motion for Mineral Scenario
Ground Motion Hazard and Geotechnical Assessment
Washington Monument
Washington, District of Colombia

By: DG	Date: 4/23/2012	Project No. OD12162670
amec		Figure **C-1a**

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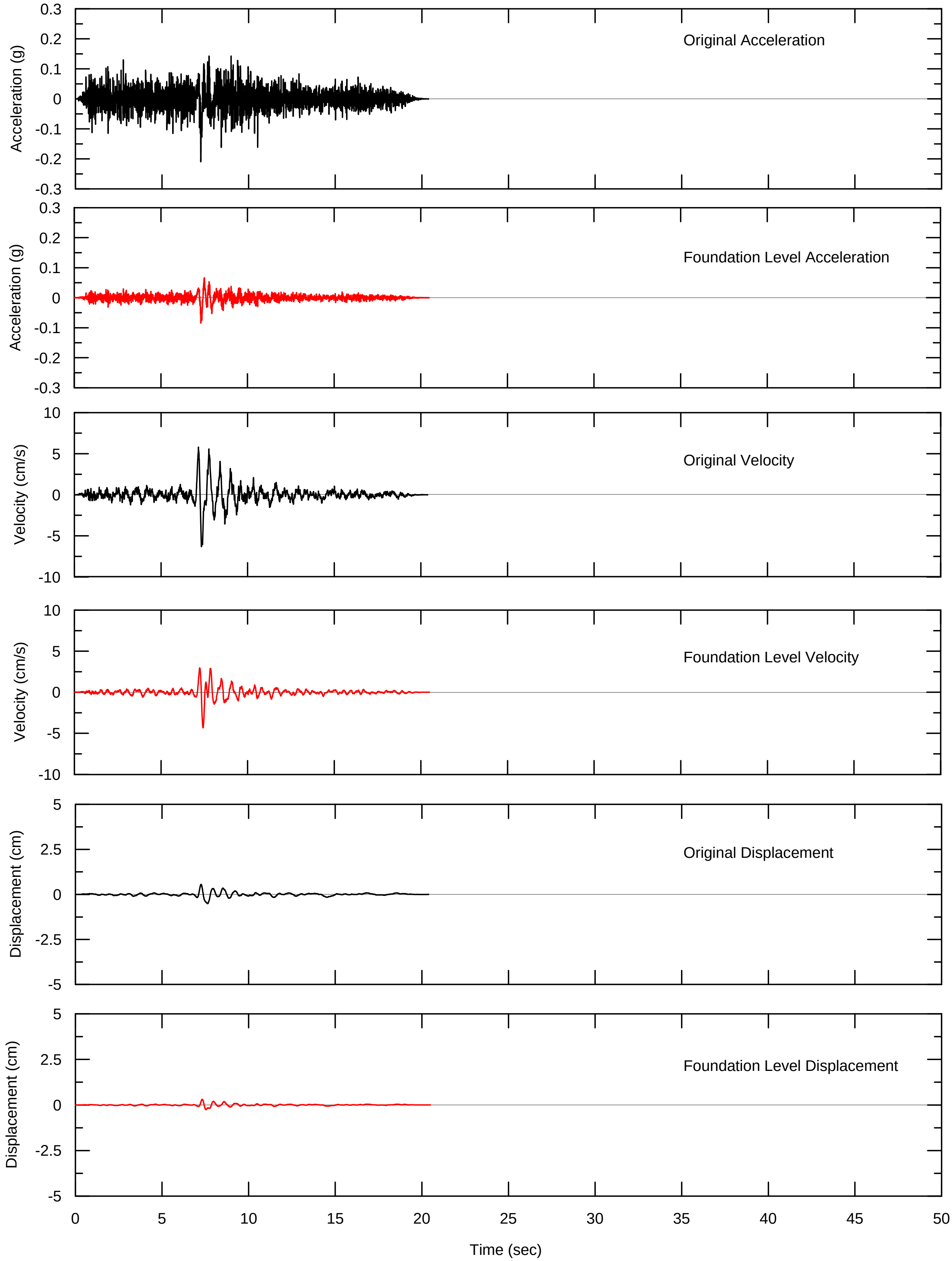

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1986, N. Palm Springs, Anza - Tule Canyon, 270 Foundation Level Motion for Mineral Scenario GMHGA,Washington Monument	By: DG	Date: 4/23/2012	Project No. OD12162670
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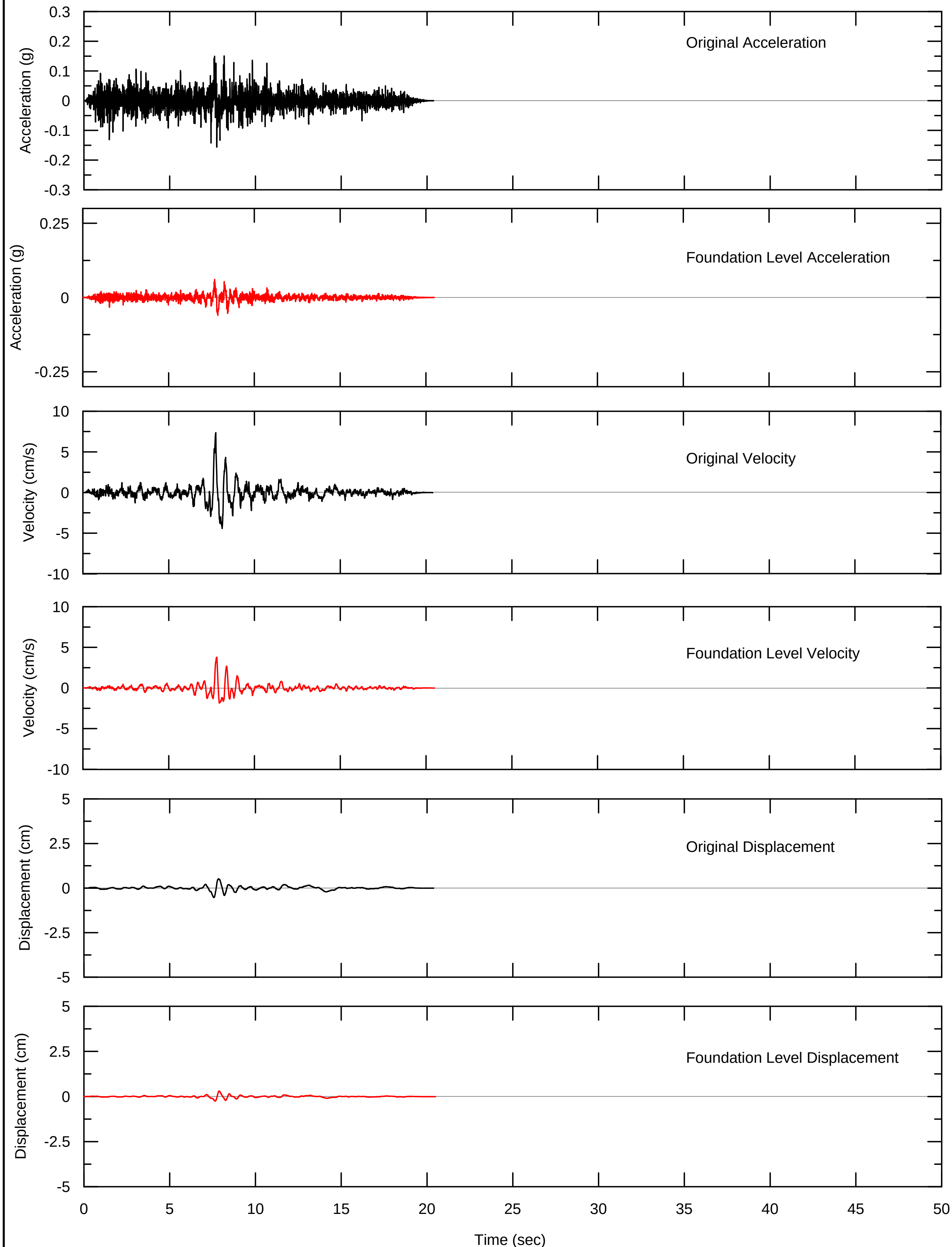

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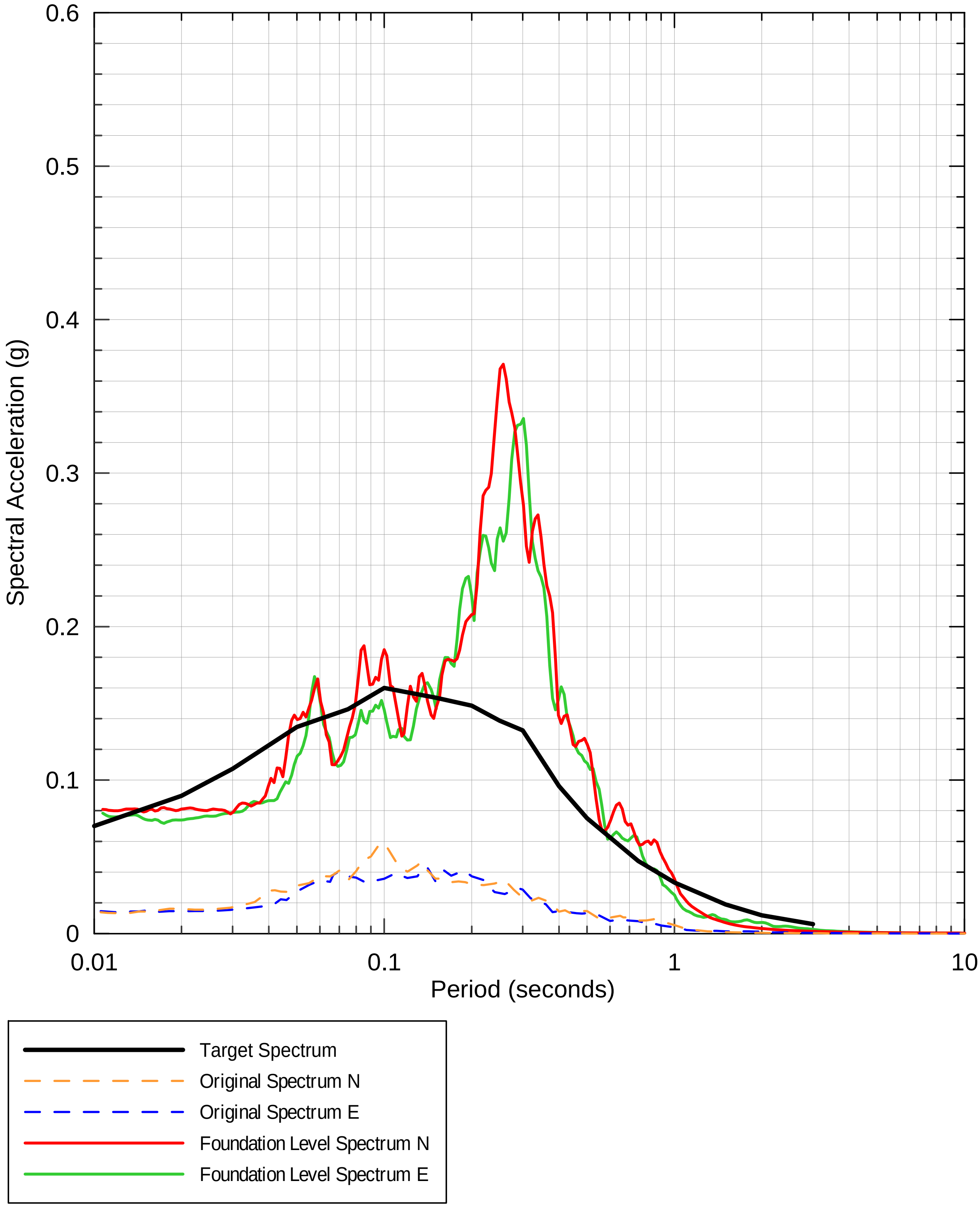

Horizontal Response Spectra
1988, Saguenay, ECTN:A64
Foundation Level Motion for Mineral Scenario
Ground Motion Hazard and Geotechnical Assessment
Washington Monument
Washington, District of Colombia

By: DG	Date: 4/23/2012	Project No. OD12162670
amec		Figure **C-2a**

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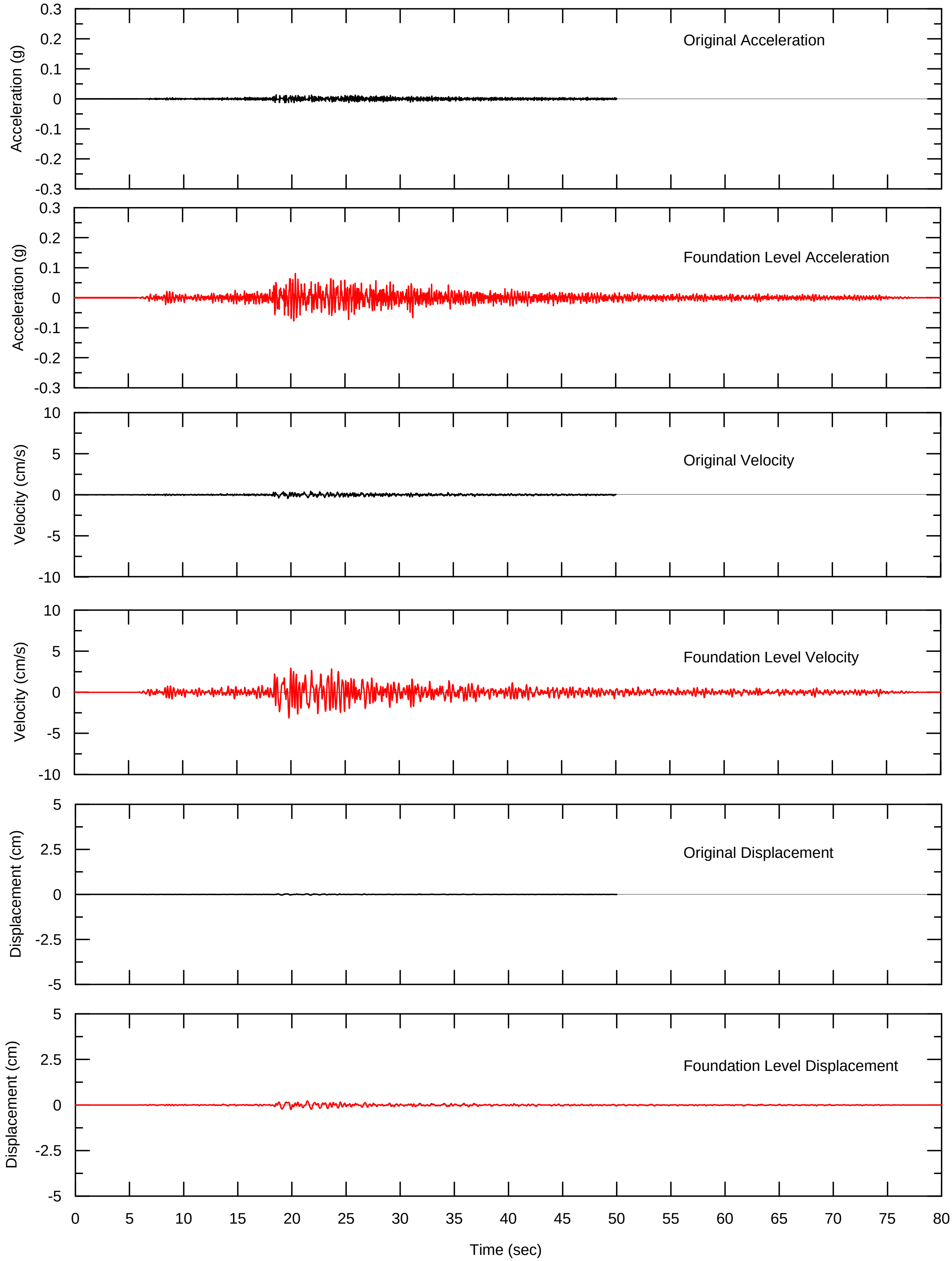

1988, Saguenay, ECTN:A64, N Foundation Level Motion for Mineral Scenario GMHGA,Washington Monument	By: DG	Date: 4/23/2012	Project No. OD12162670
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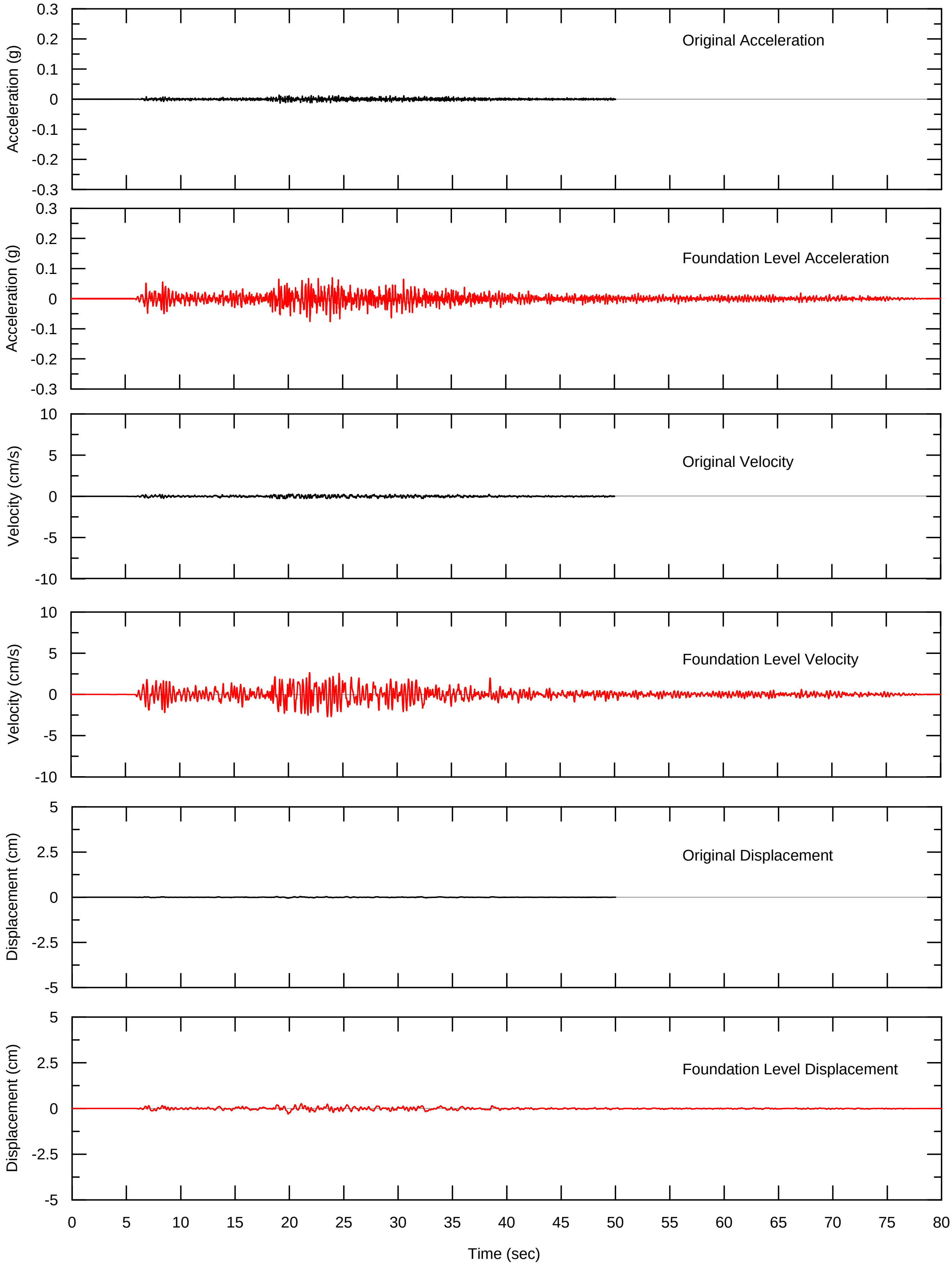

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1988, Saguenay, ECTN:A64, E Foundation Level Motion for Mineral Scenario GMHGA,Washington Monument	By: DG	Date: 4/23/2012	Project No. OD12162670
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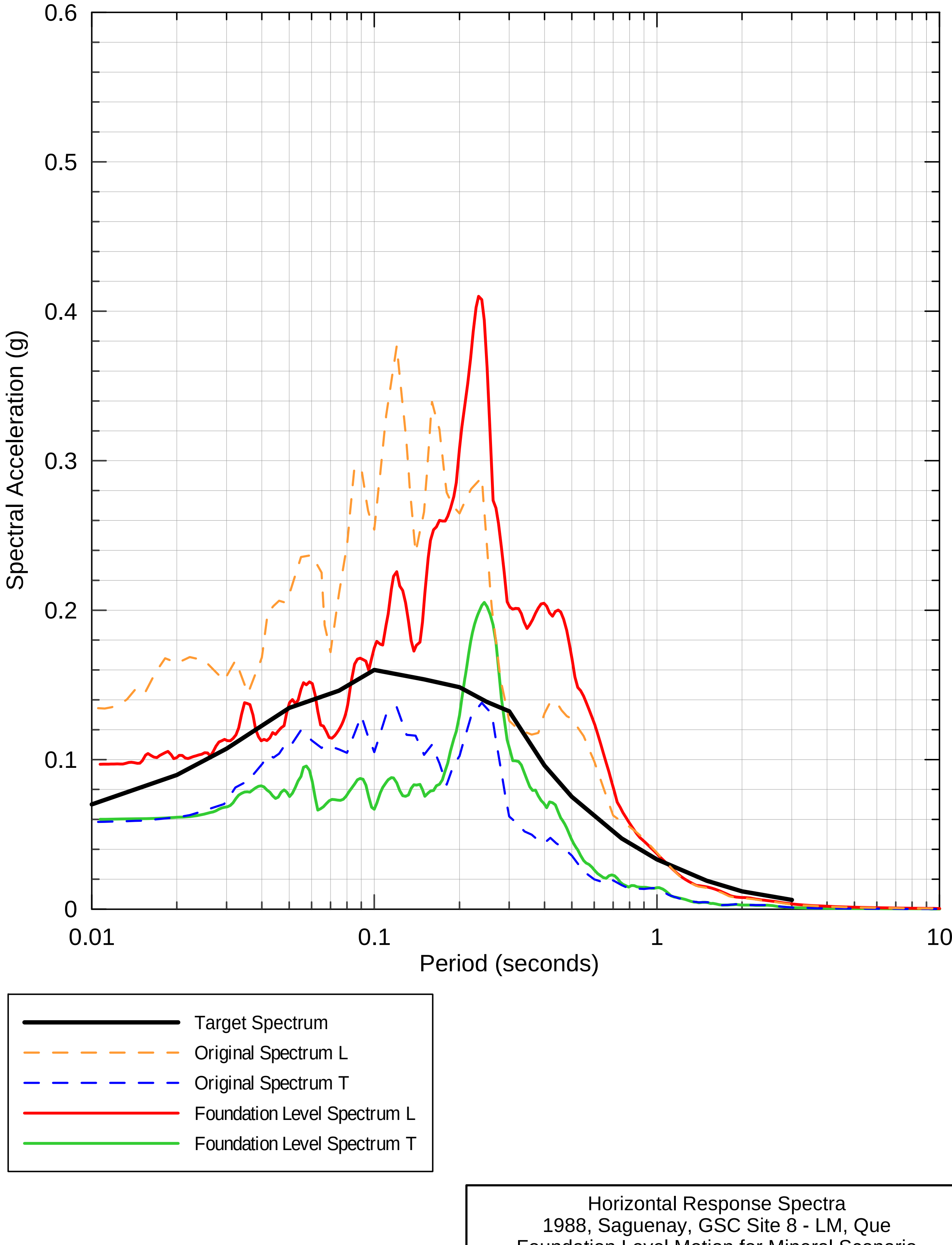

Horizontal Response Spectra
1988, Saguenay, GSC Site 8 - LM, Que
Foundation Level Motion for Mineral Scenario
Ground Motion Hazard and Geotechnical Assessment
Washington Monument
Washington, District of Colombia

By: DG	Date: 4/23/2012	Project No. OD12162670
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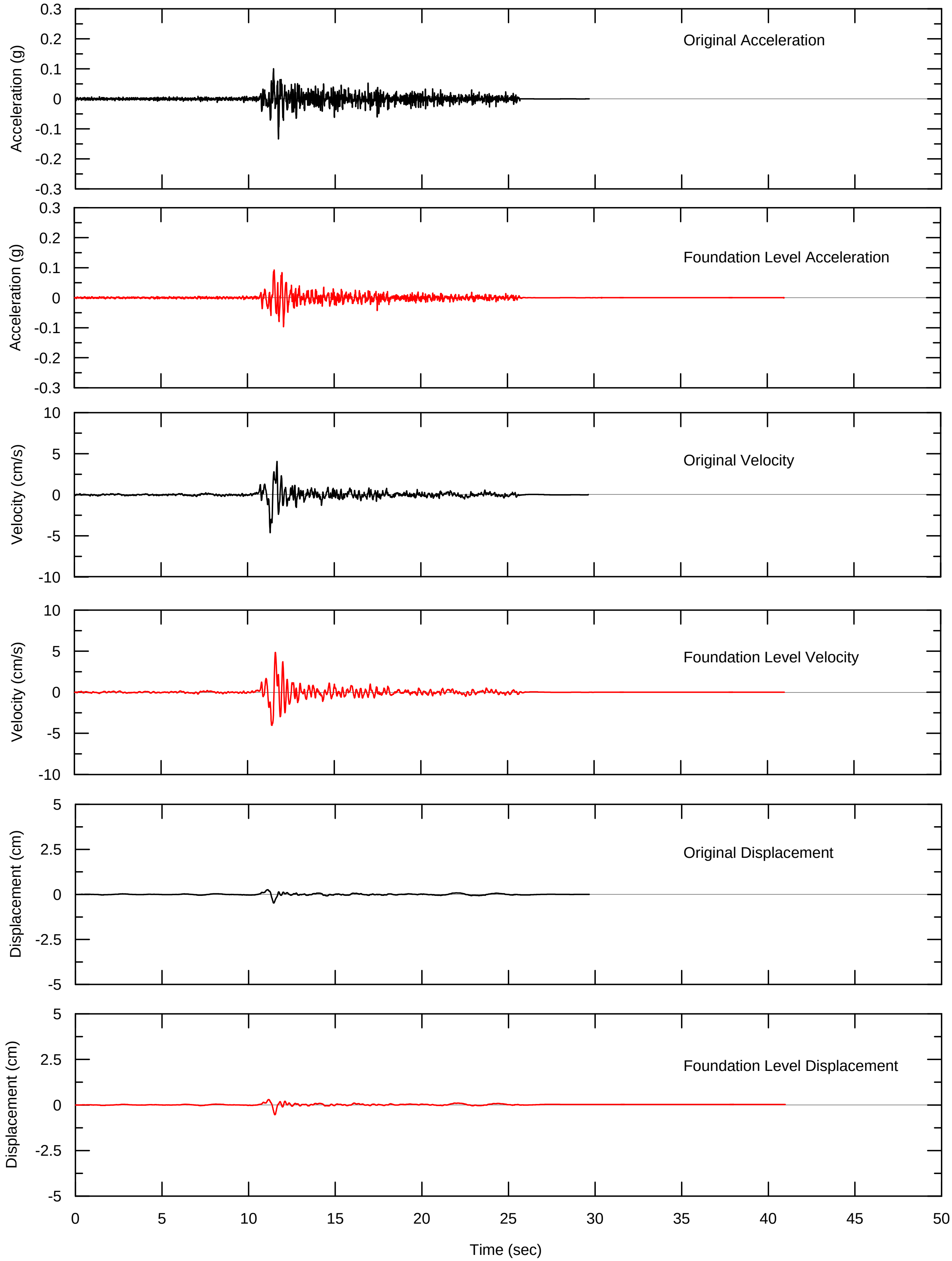

1988, Saguenay, GSC Site 8 - LM, Que, L Foundation Level Motion for Mineral Scenario GMHGA,Washington Monument	By: DG	Date: 4/23/2012	Project No. OD12162670
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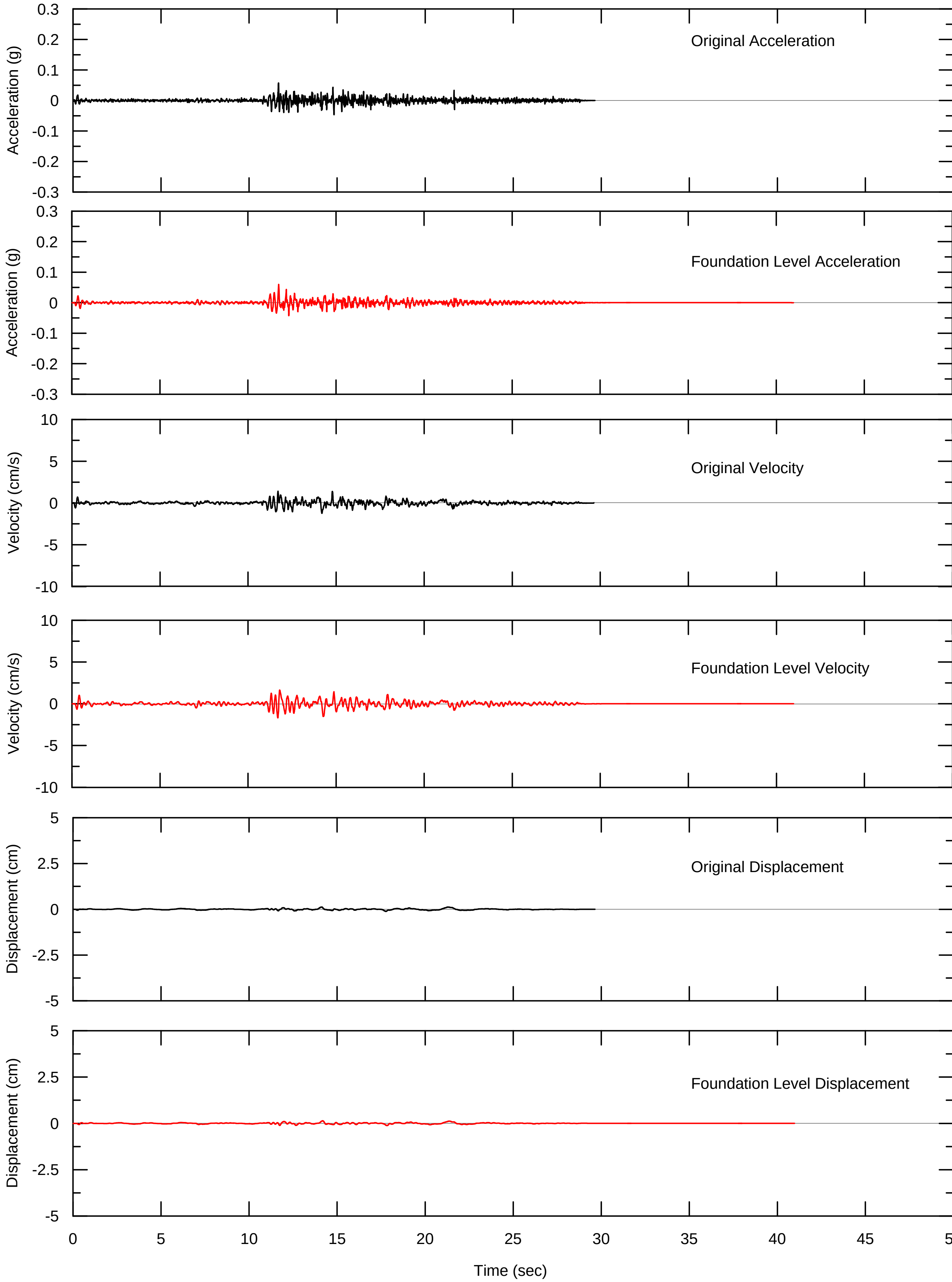

1988, Saguenay, GSC Site 8 - LM, Que, T Foundation Level Motion for Mineral Scenario GMHGA,Washington Monument	By: DG	Date: 4/23/2012	Project No. OD12162670
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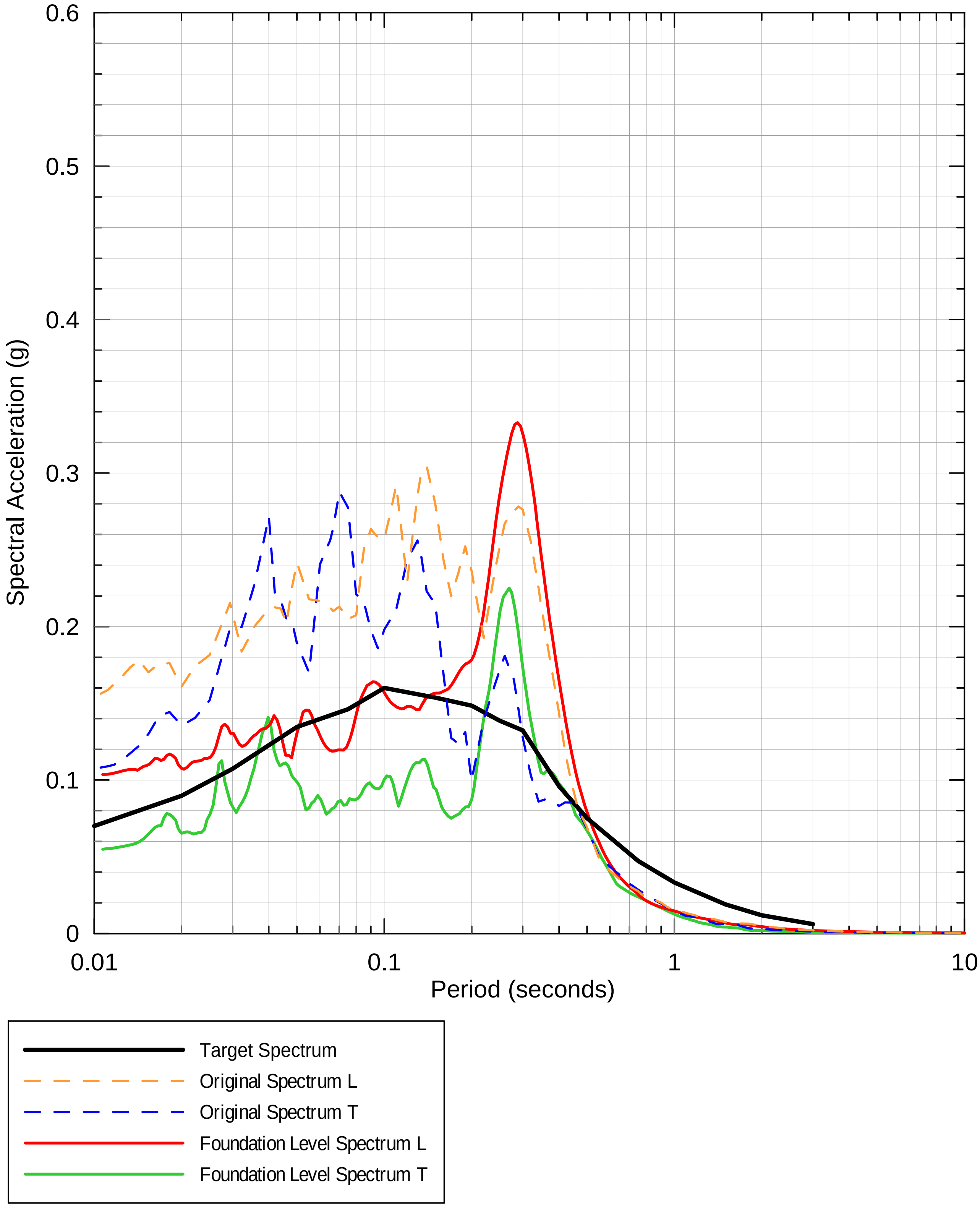

Horizontal Response Spectra
1988, Saguenay, GSC Site 20 - LE
Foundation Level Motion for Mineral Scenario
Ground Motion Hazard and Geotechnical Assessment
Washington Monument
Washington, District of Colombia

By: DG	Date: 4/23/2012	Project No. OD12162670
amec		Figure **C-4a**

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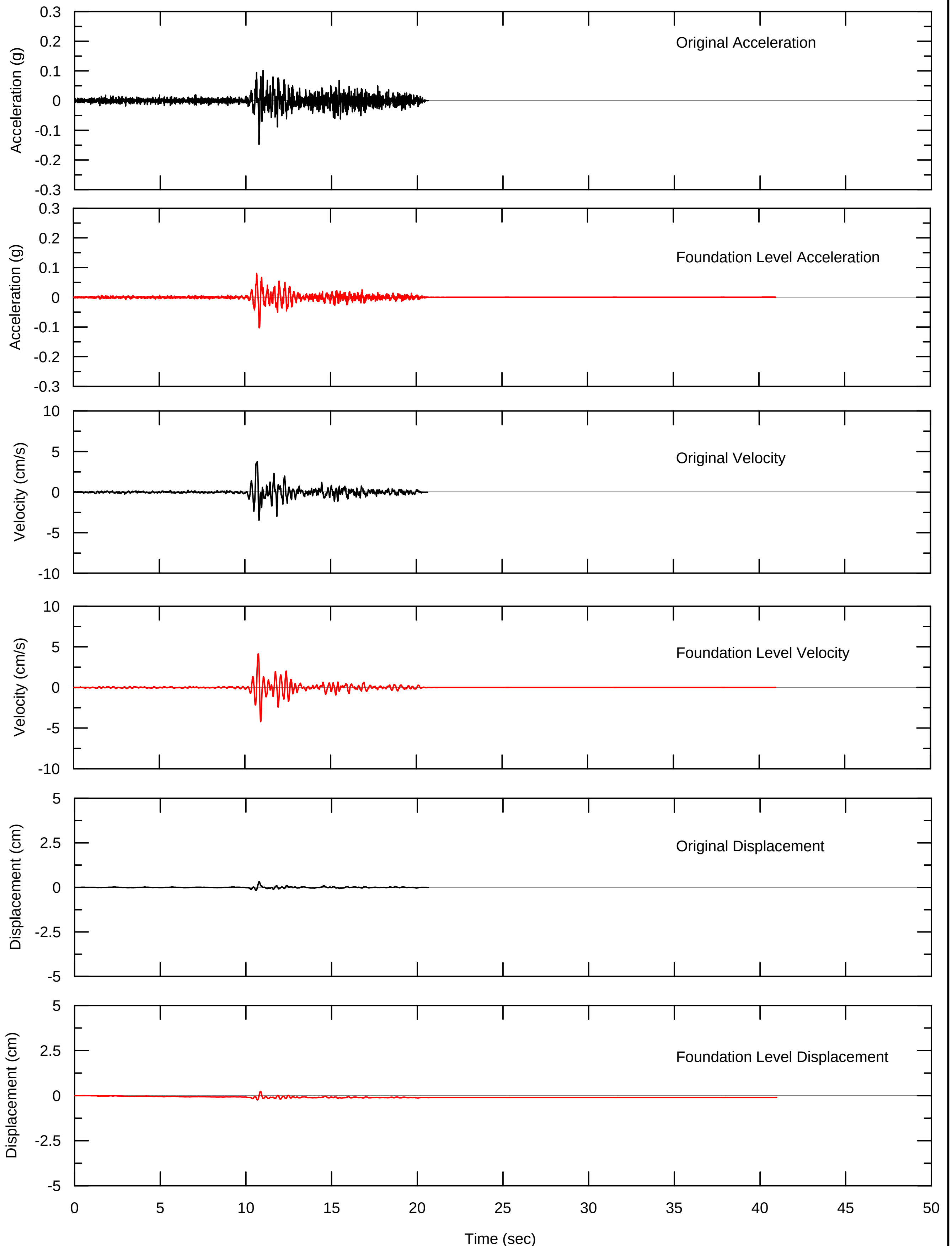

1988, Saguenay, GSC Site 20 - LE, L Foundation Level Motion for Mineral Scenario GMHGA,Washington Monument	By: DG	Date: 4/23/2012	Project No. OD12162670
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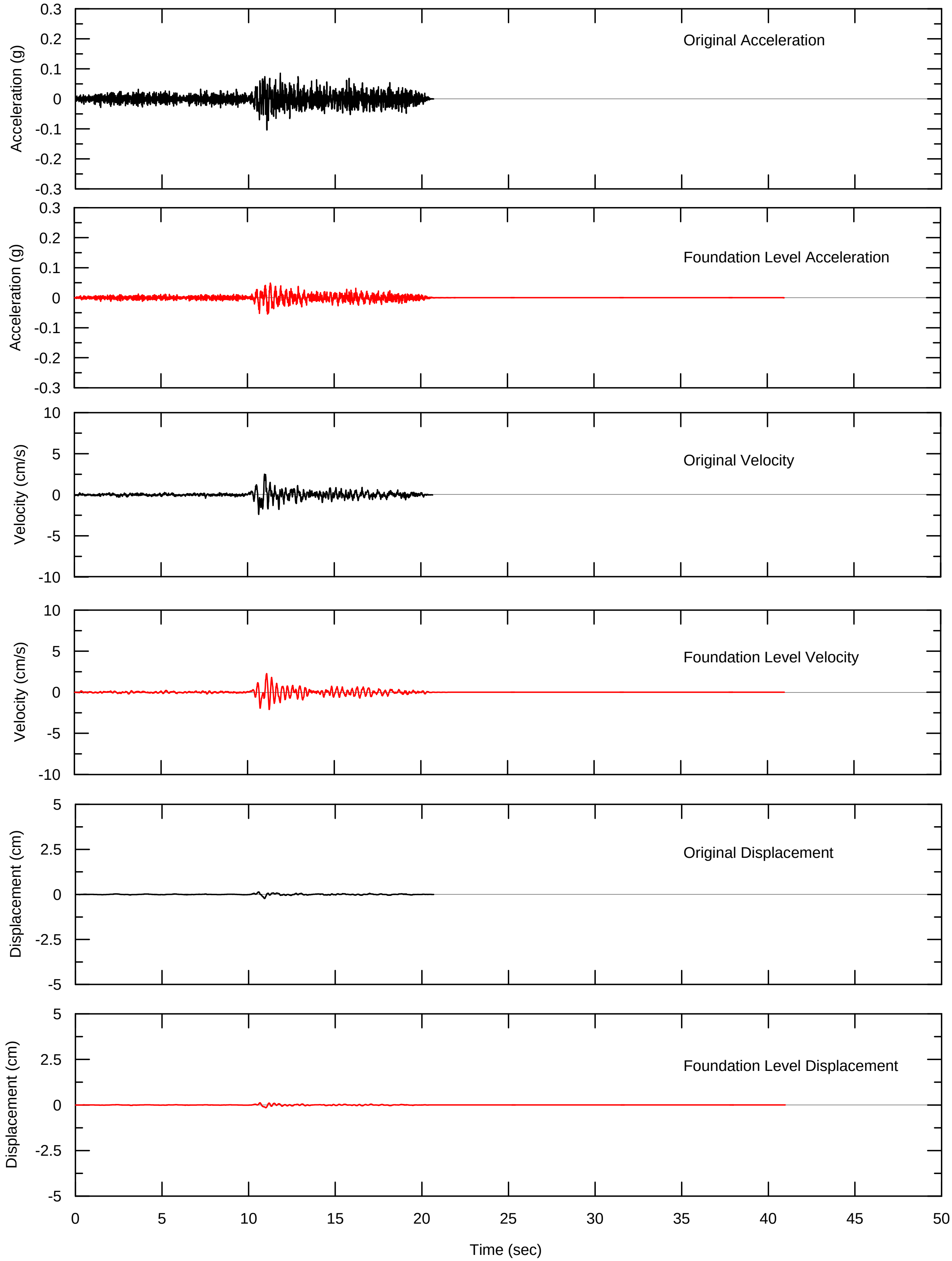

1988, Saguenay, GSC Site 20 - LE, T
Foundation Level Motion for Mineral Scenario
GMHGA,Washington Monument

By: DG	Date: 4/23/2012	Project No. OD12162670
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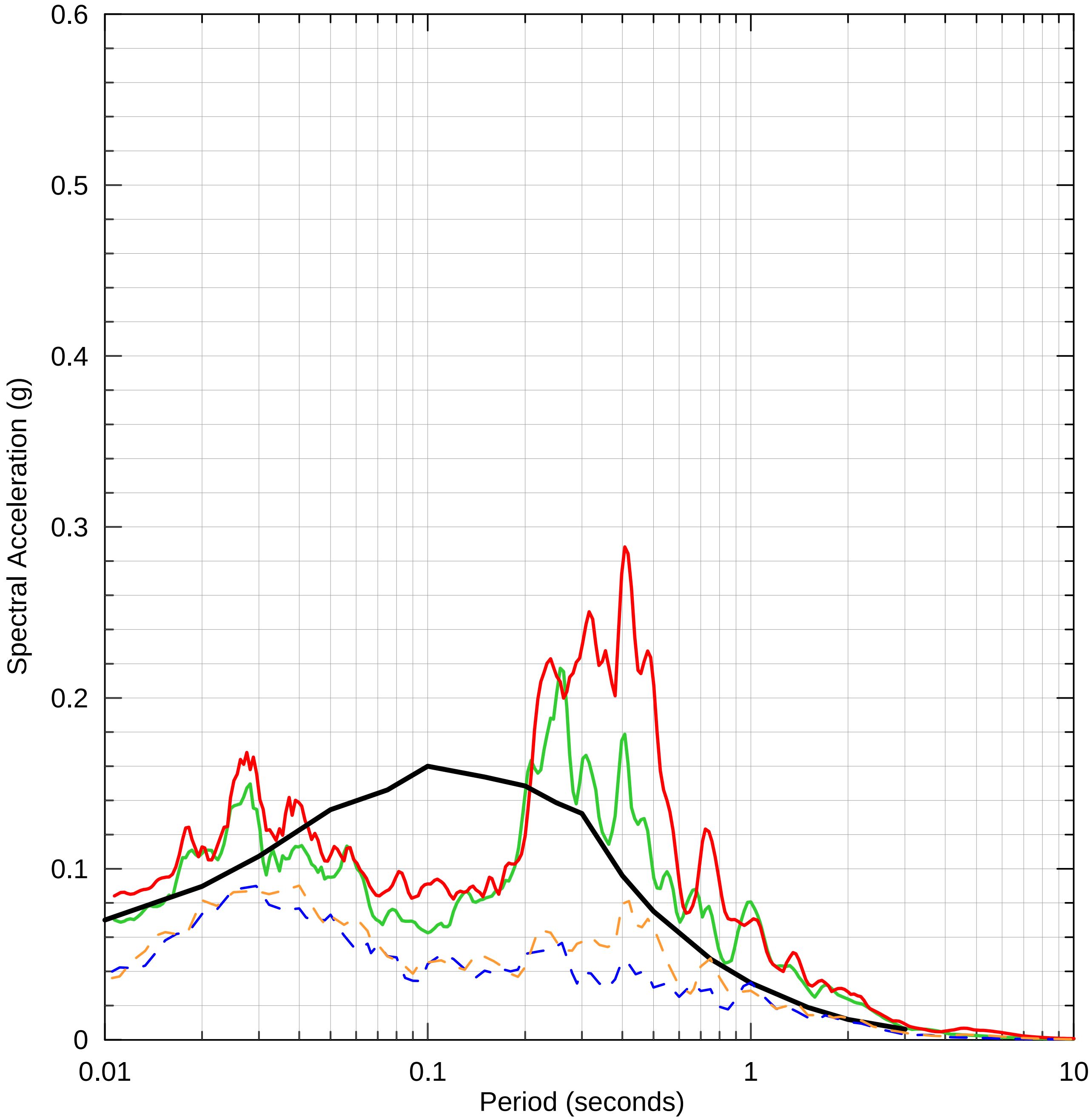

Horizontal Response Spectra
1991, Georgia, USSR, Ambralauri
Foundation Level Motion for Mineral Scenario
Ground Motion Hazard and Geotechnical Assessment
Washington Monument
Washington, District of Colombia

By: DG	Date: 4/23/2012	Project No. OD12162670
amec		Figure **C-5a**

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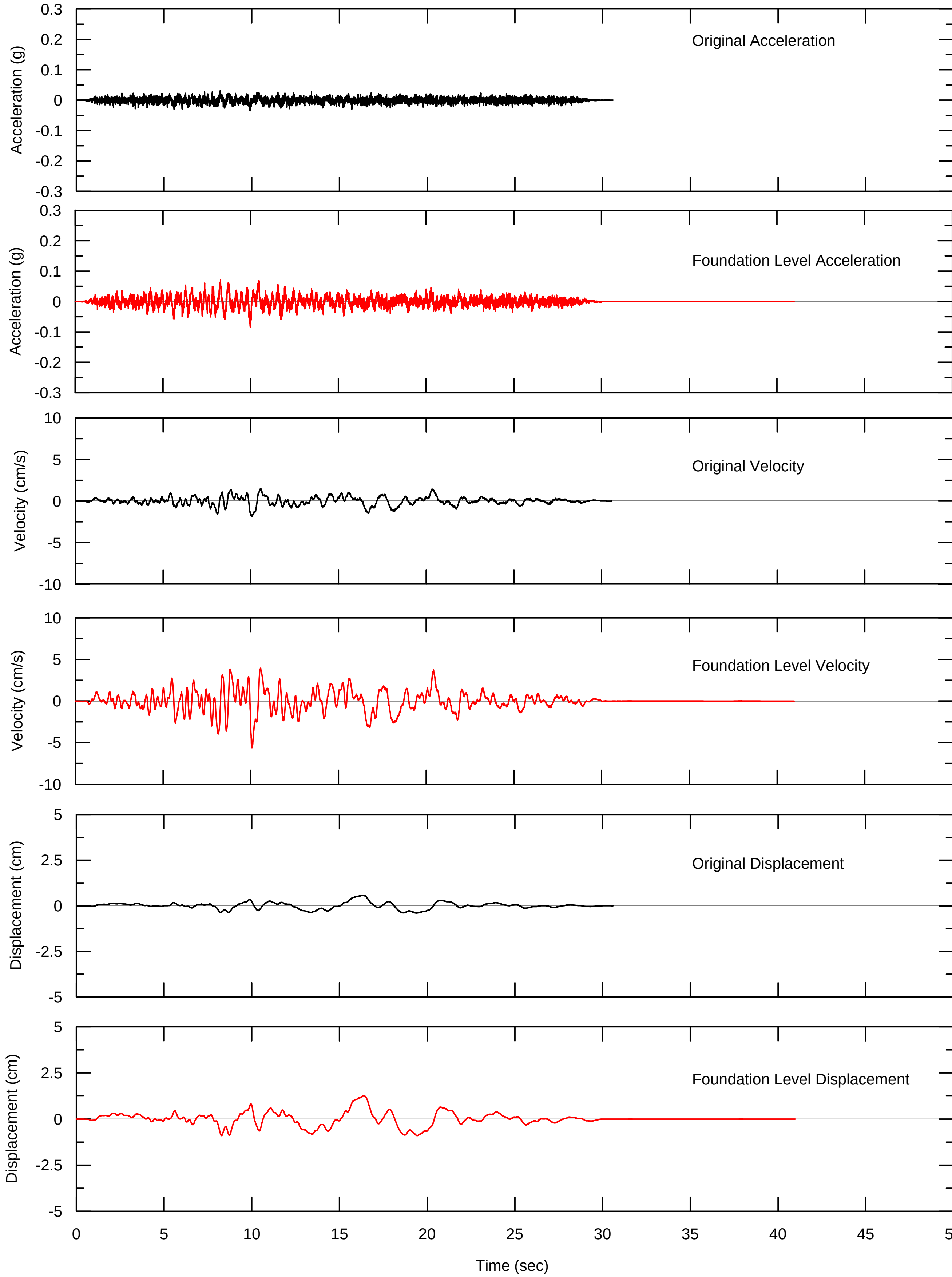

1991, Georgia, USSR, Ambralauri, X
Foundation Level Motion for Mineral Scenario
GMHGA,Washington Monument

By: DG	Date: 4/23/2012	Project No. OD12162670
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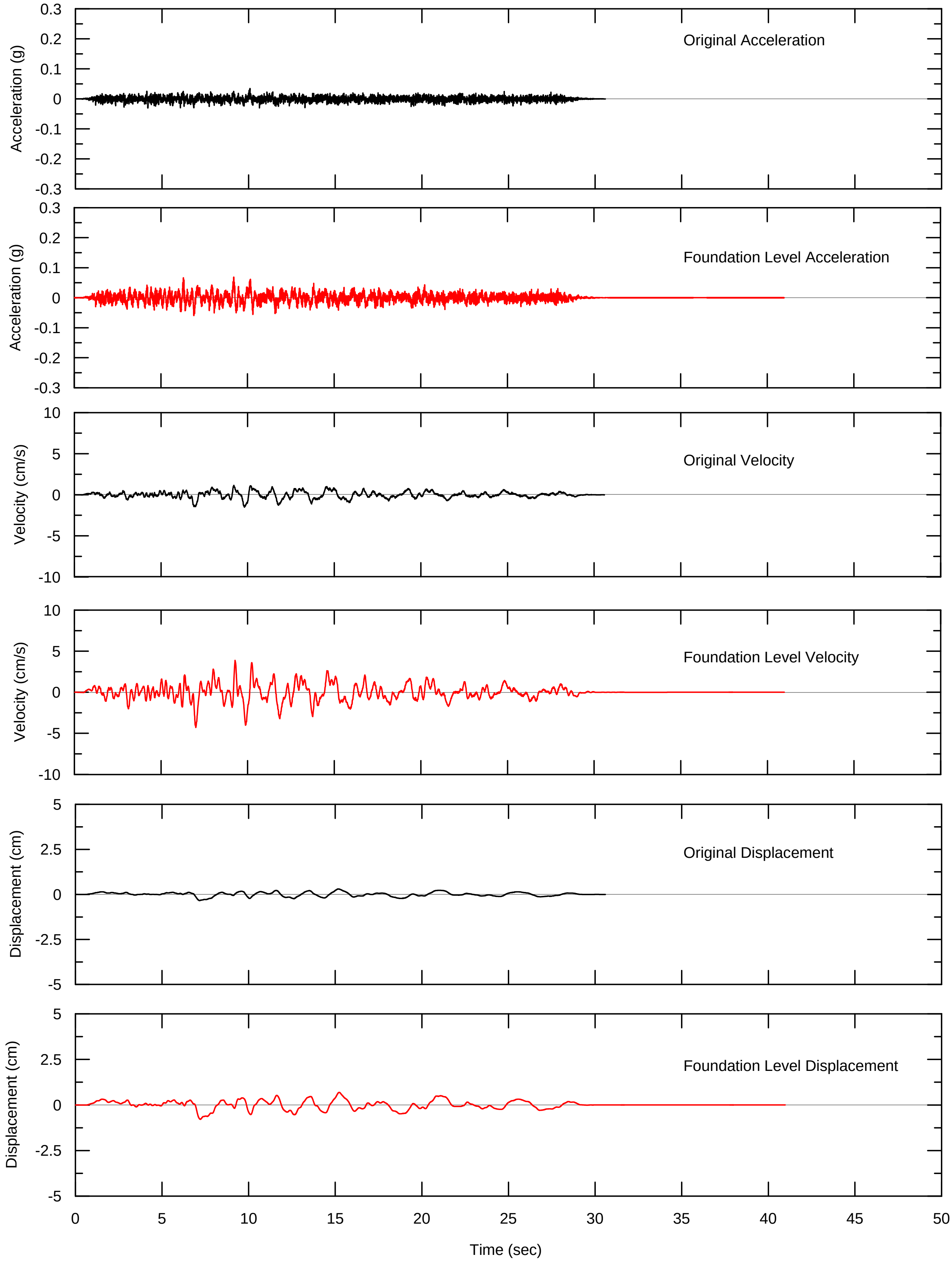

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1991, Georgia, USSR, Ambralauri, Y Foundation Level Motion for Mineral Scenario GMHGA,Washington Monument	By: DG	Date: 4/23/2012	Project No. OD12162670
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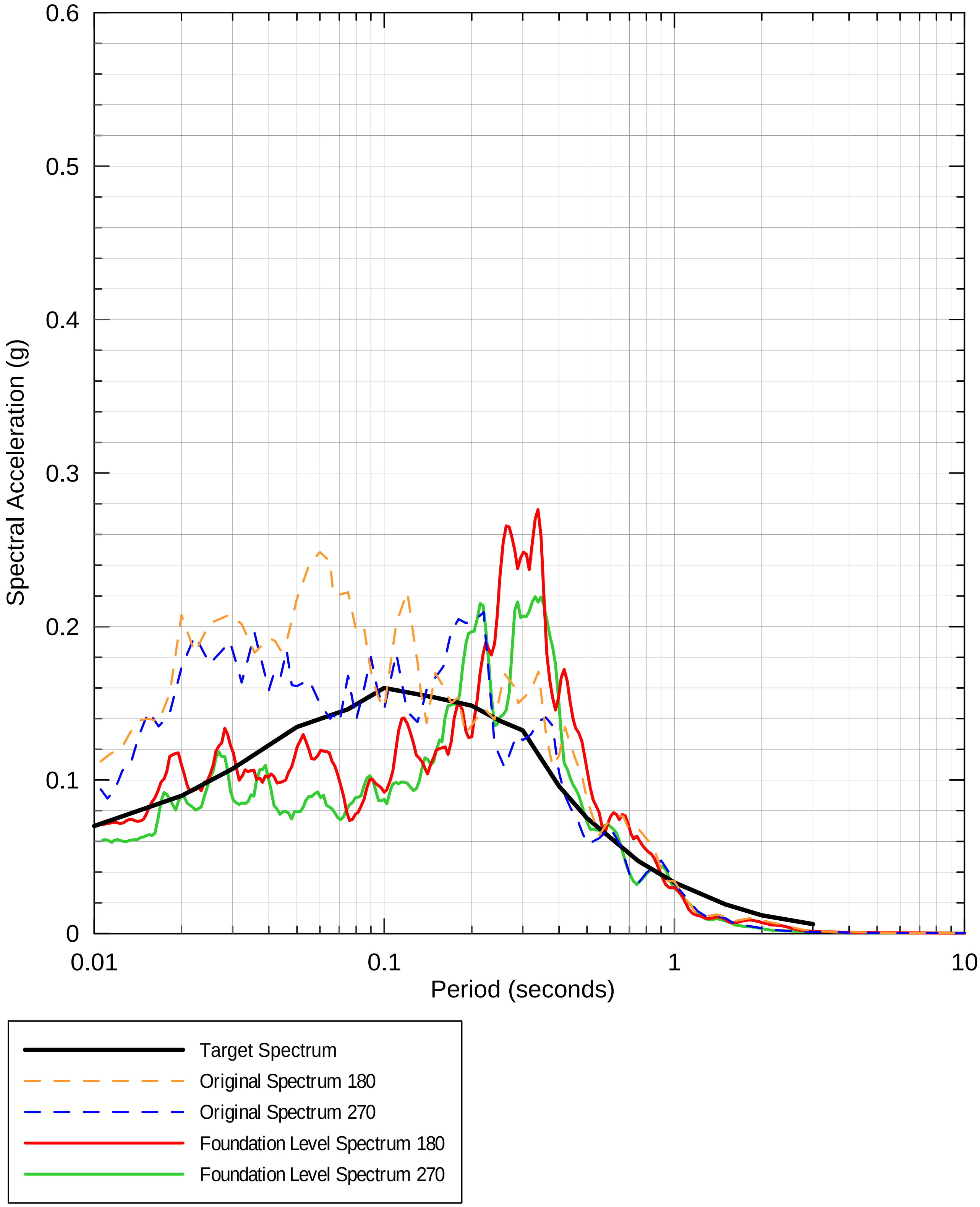

Horizontal Response Spectra
1987, Whittier Narrows, Malibu - PDS
Foundation Level Motion for Mineral Scenario
Ground Motion Hazard and Geotechnical Assessment
Washington Monument
Washington, District of Colombia

By: DG	Date: 4/23/2012	Project No. OD12162670
amec		Figure **C-6a**

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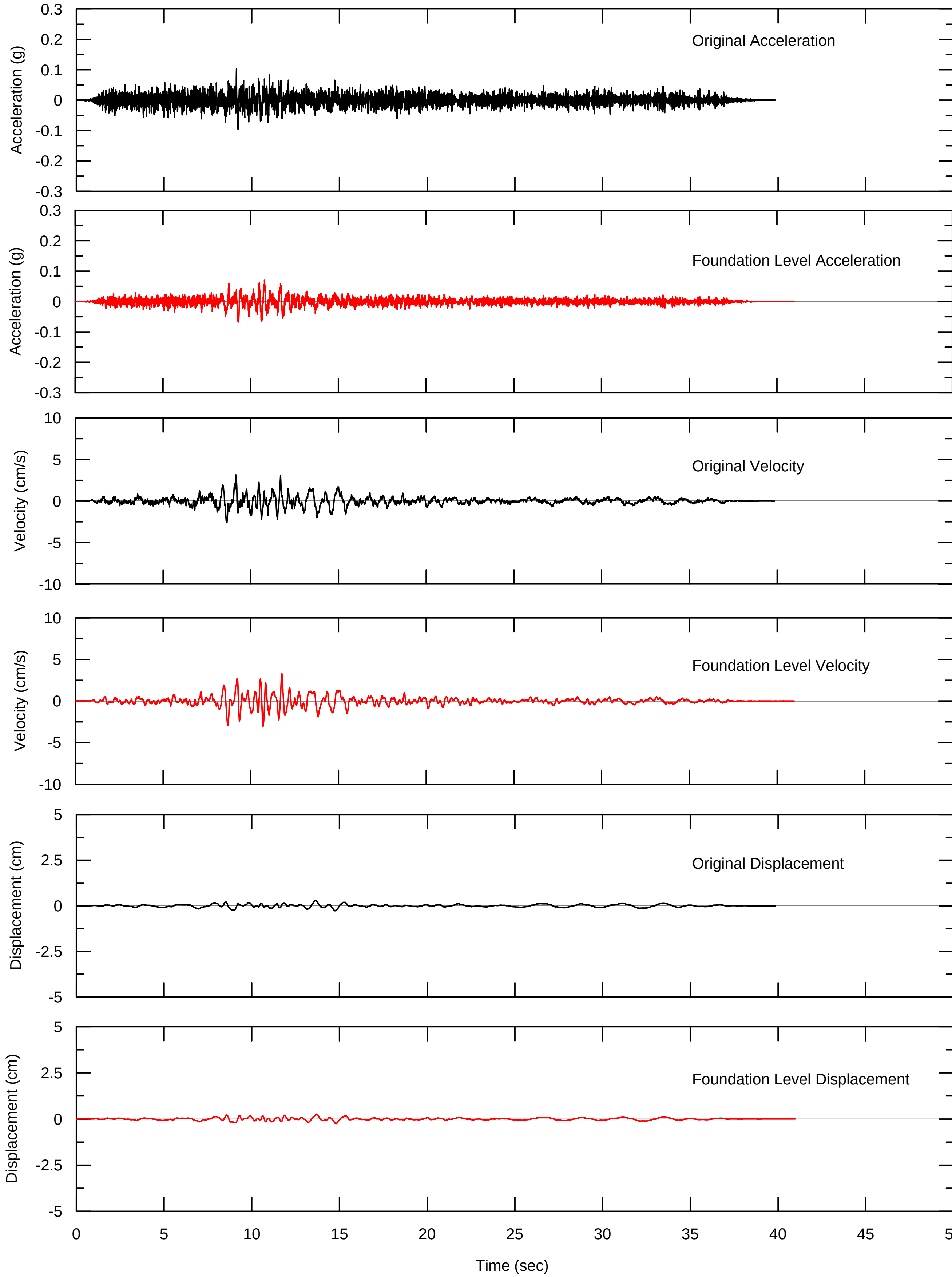

1987, Whittier Narrows, Malibu - PDS, 180 Foundation Level Motion for Mineral Scenario GMHGA,Washington Monument	By: DG	Date: 4/23/2012	Project No. OD12162670
	amec		Figure **C-6b**

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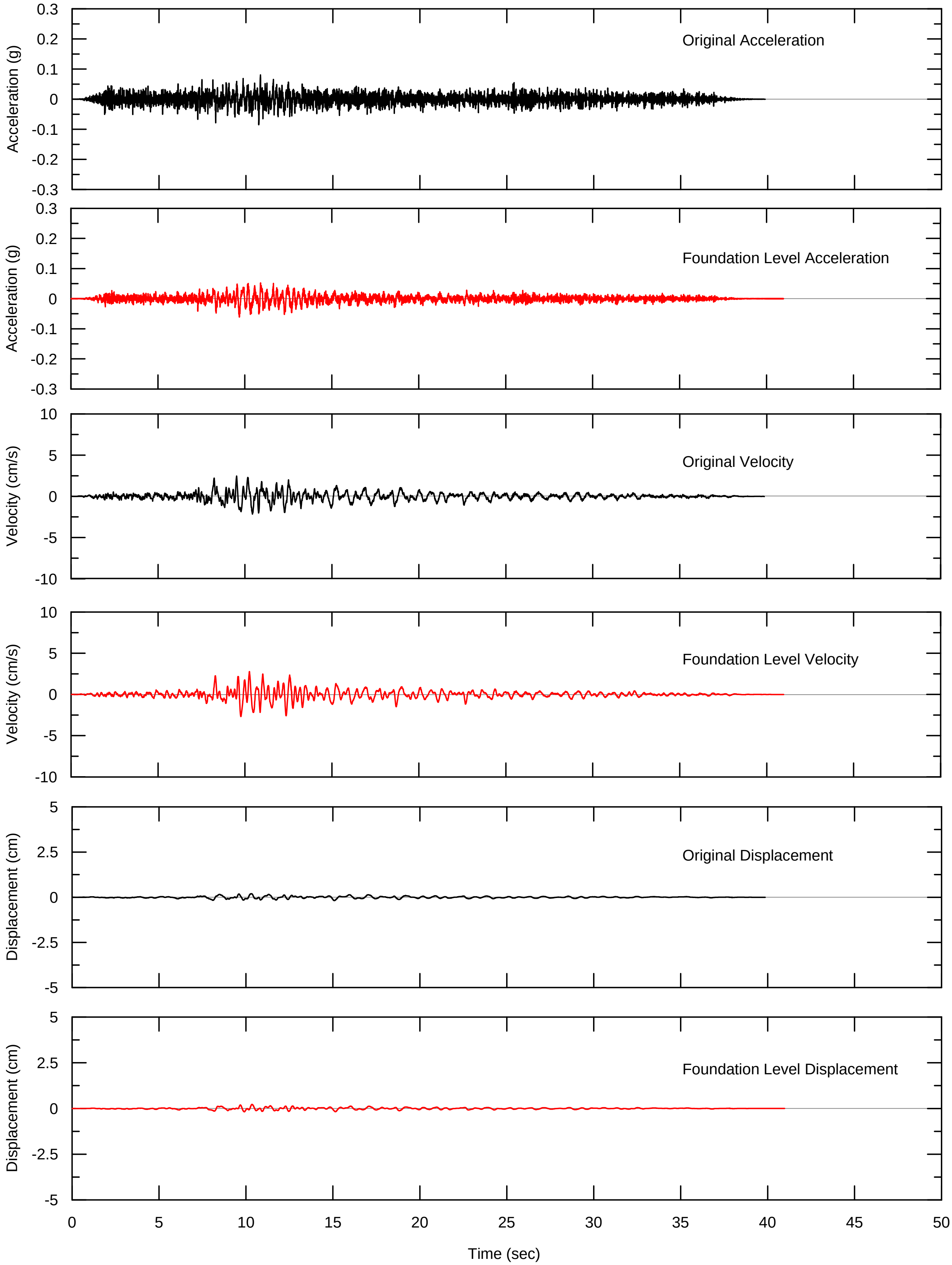

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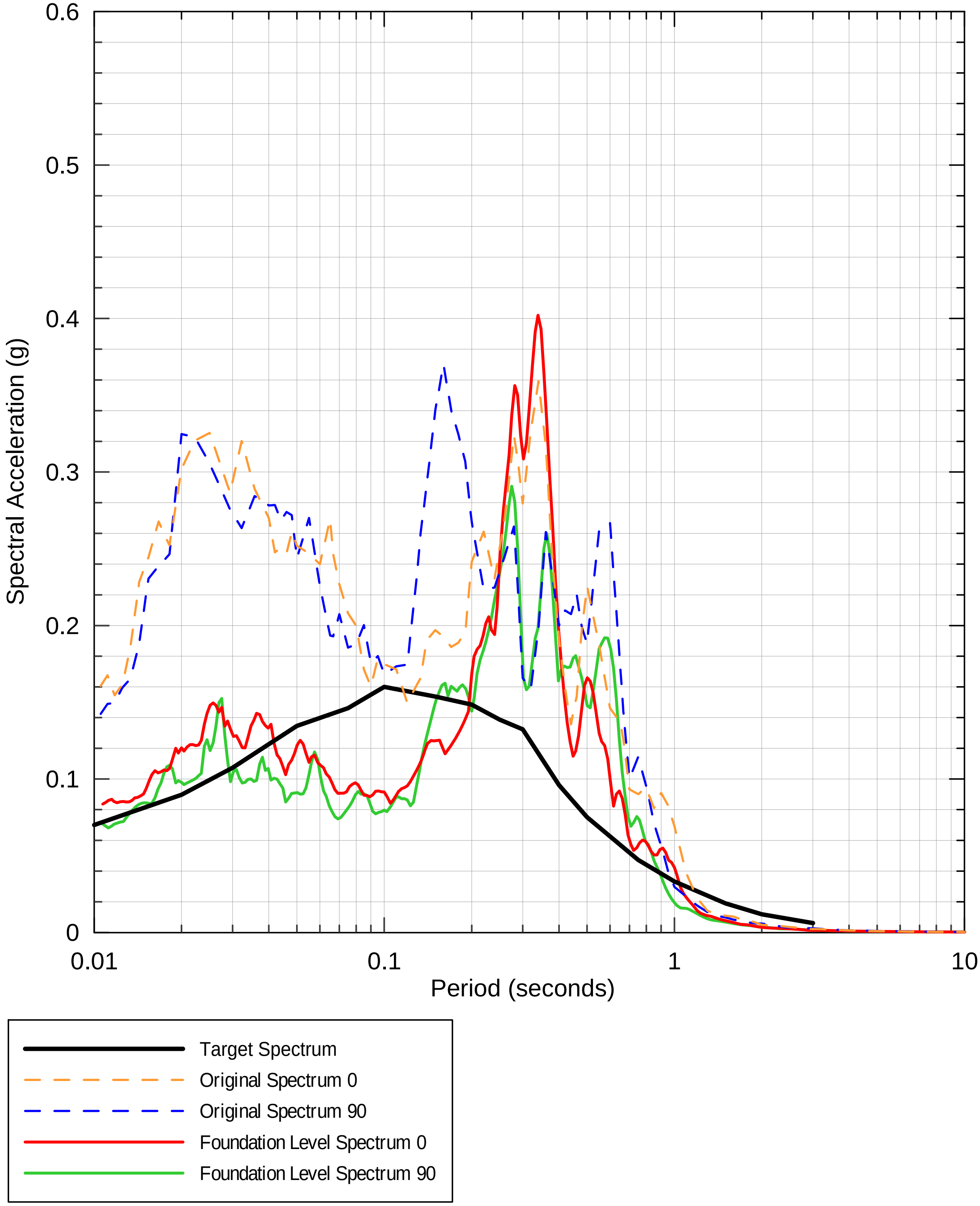
1987, Whittier Narrows, Malibu - PDS, 270 Foundation Level Motion for Mineral Scenario GMHGA,Washington Monument	By: DG	Date: 4/23/2012	Project No. OD12162670
	amec		Figure **C-6c**



Horizontal Response Spectra
1987, Whittier Narrows, Castaic - ORR
Foundation Level Motion for Mineral Scenario
Ground Motion Hazard and Geotechnical Assessment
Washington Monument
Washington, District of Colombia

By: DG	Date: 4/23/2012	Project No. OD12162670
amec		Figure **C-7a**

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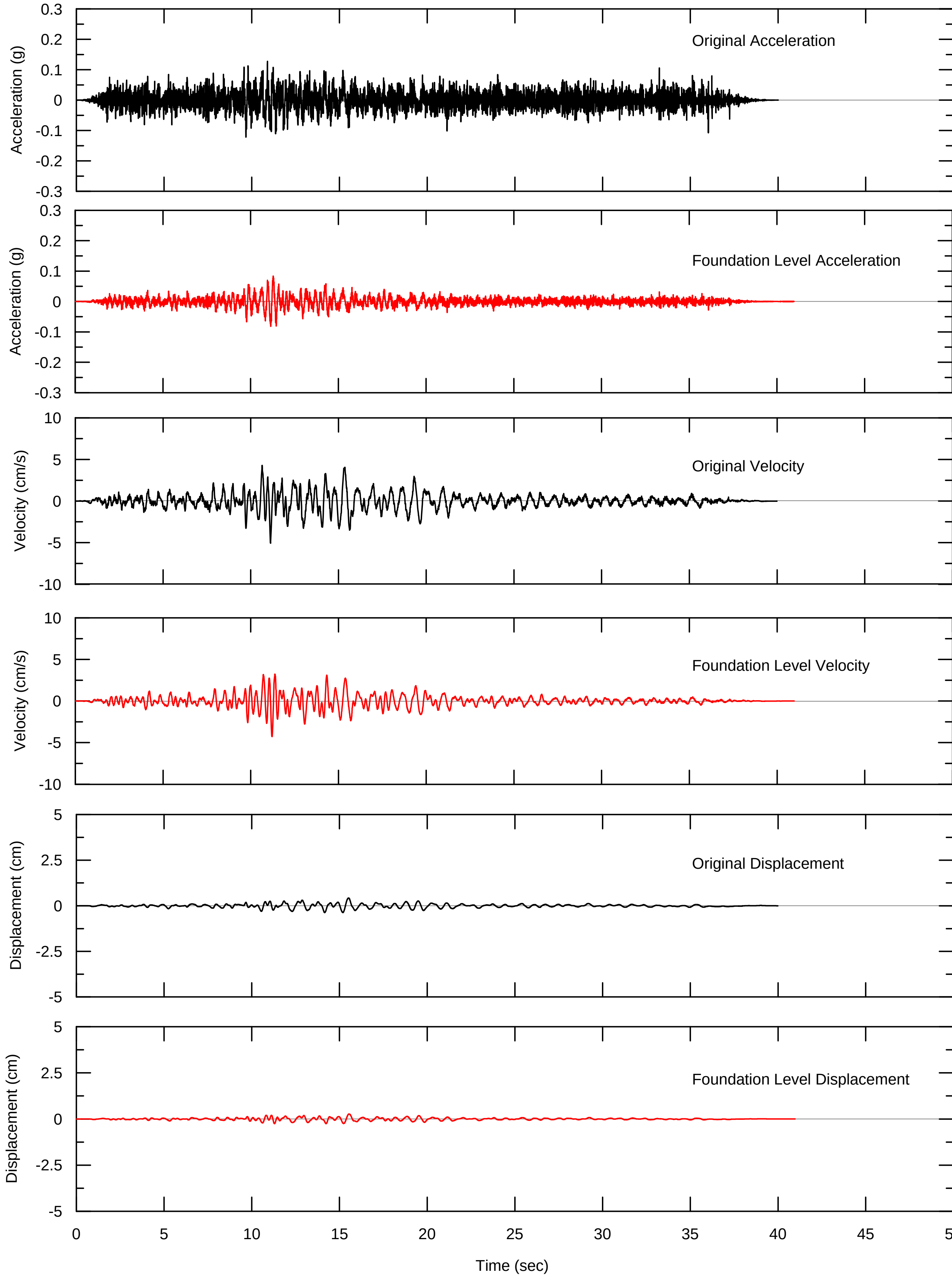

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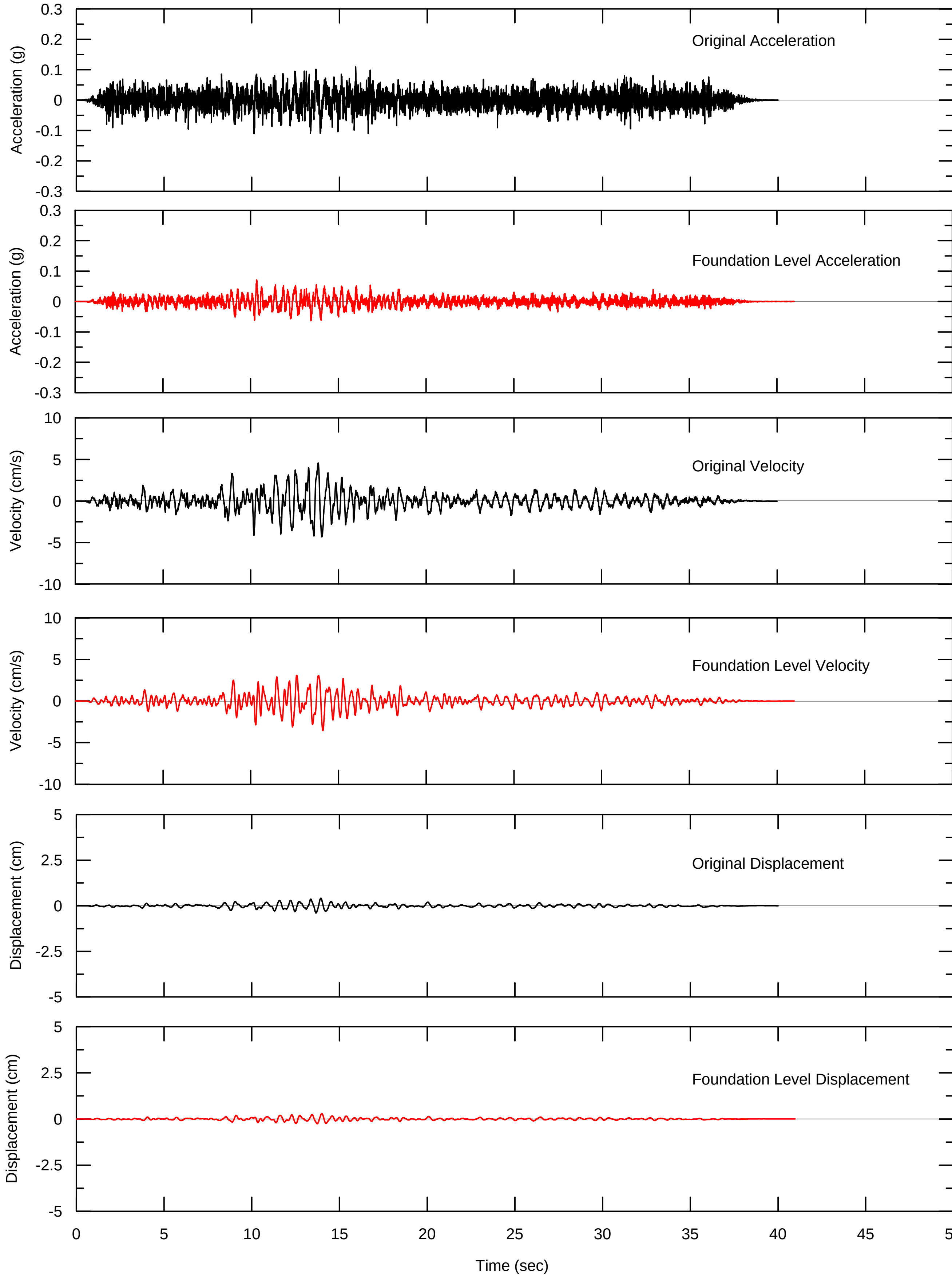
1987, Whittier Narrows, Castaic - ORR, 0 Foundation Level Motion for Mineral Scenario GMHGA,Washington Monument	By: DG	Date: 4/23/2012	Project No. OD12162670
	amec		Figure **C-7b**



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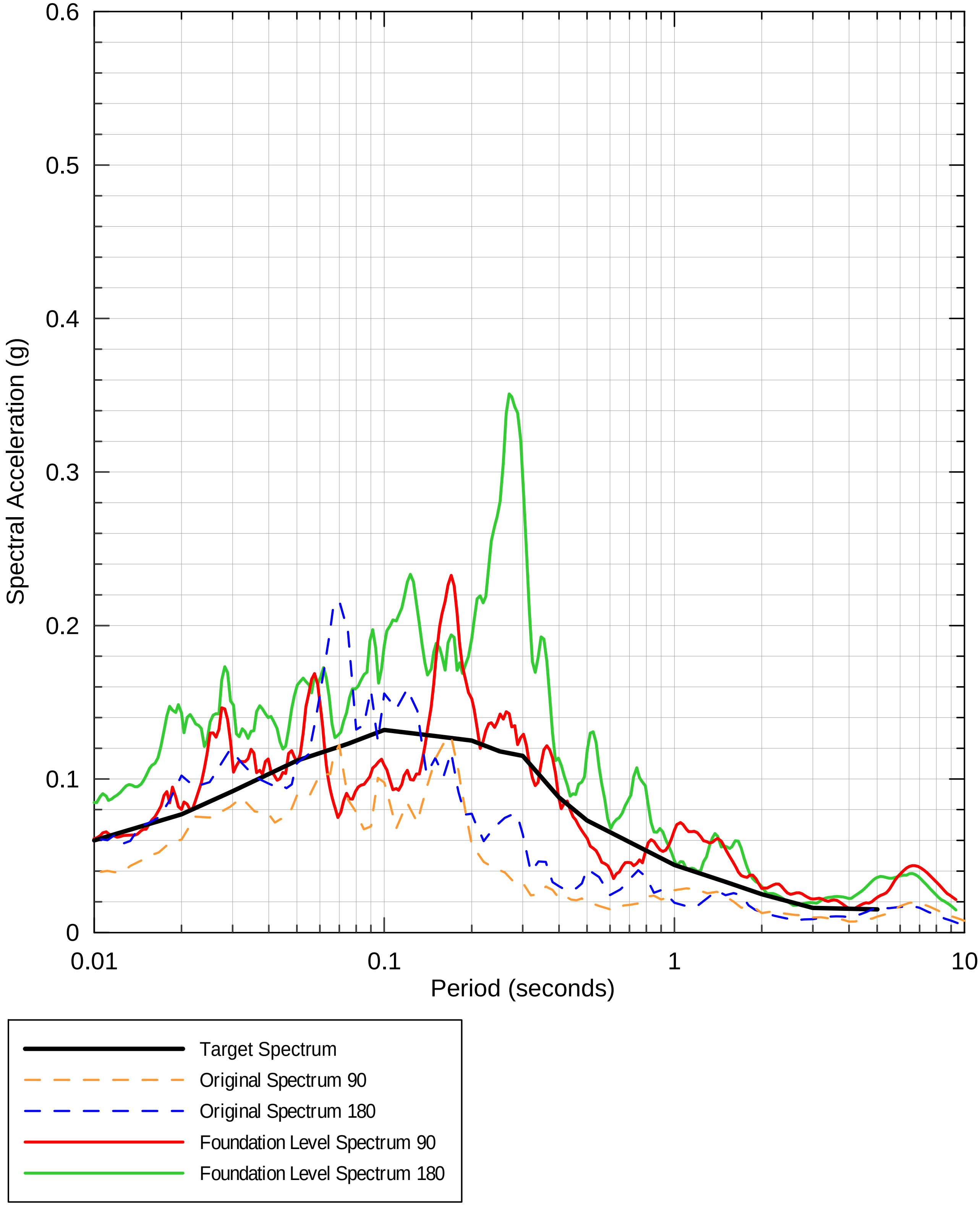
1987, Whittier Narrows, Castaic - ORR, 90 Foundation Level Motion for Mineral Scenario GMHGA,Washington Monument	By: DG	Date: 4/23/2012	Project No. OD12162670
	amec		Figure **C-7c**



Horizontal Response Spectra
1999, Duzce, Turkey, Sakarya
Foundation Level Motion for 2,475-Year RP
Ground Motion Hazard and Geotechnical Assessment
Washington Monument
Washington, District of Colombia

By: DG	Date: 4/23/2012	Project No. OD12162670
amec		Figure **C-8a**

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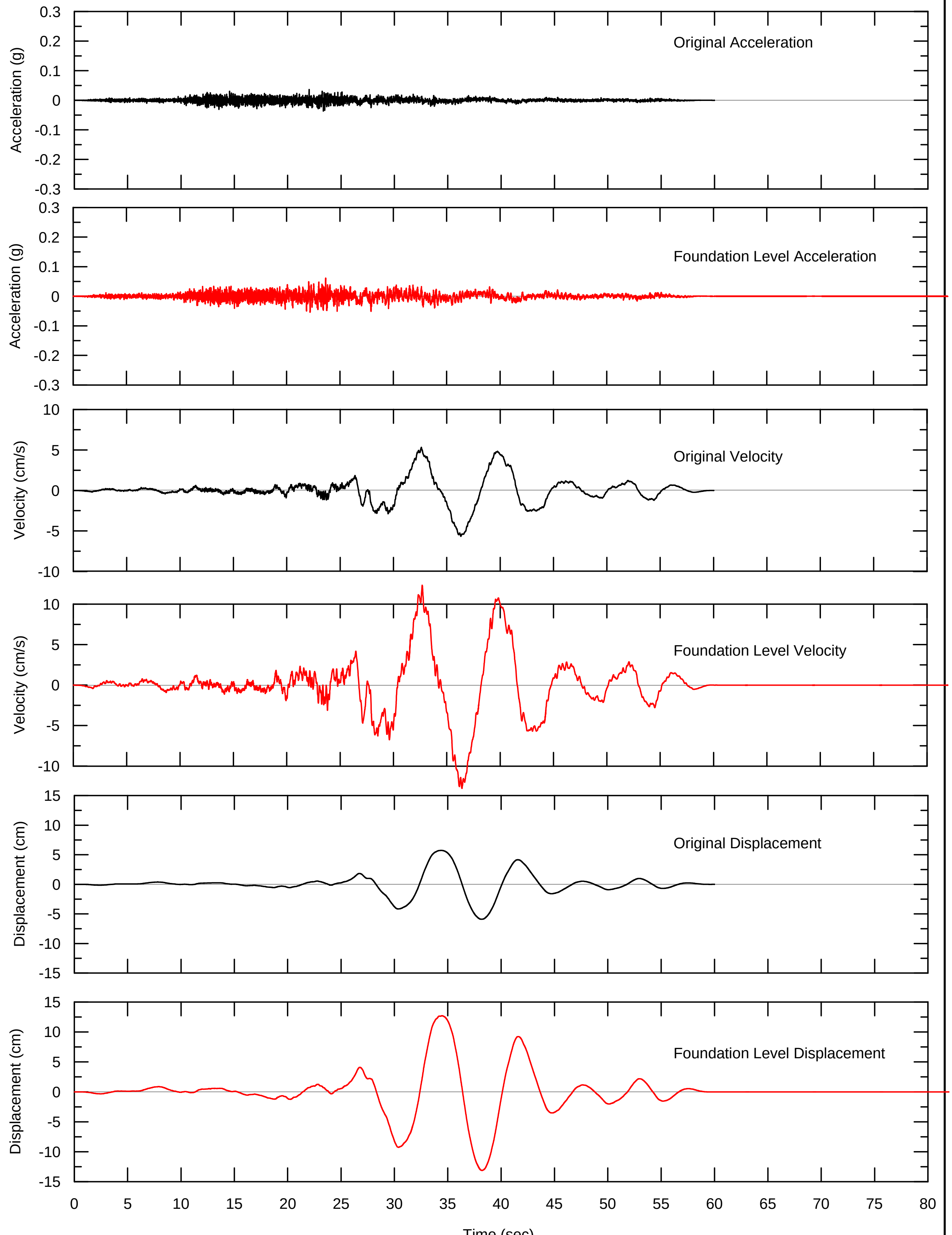

1999, Duzce, Turkey, Sakarya, 90
Foundation Level Motion for 2,475-Year RP
GMHGA,Washington Monument

By: DG	Date: 4/23/2012	Project No. OD12162670
amec		Figure **C-8b**

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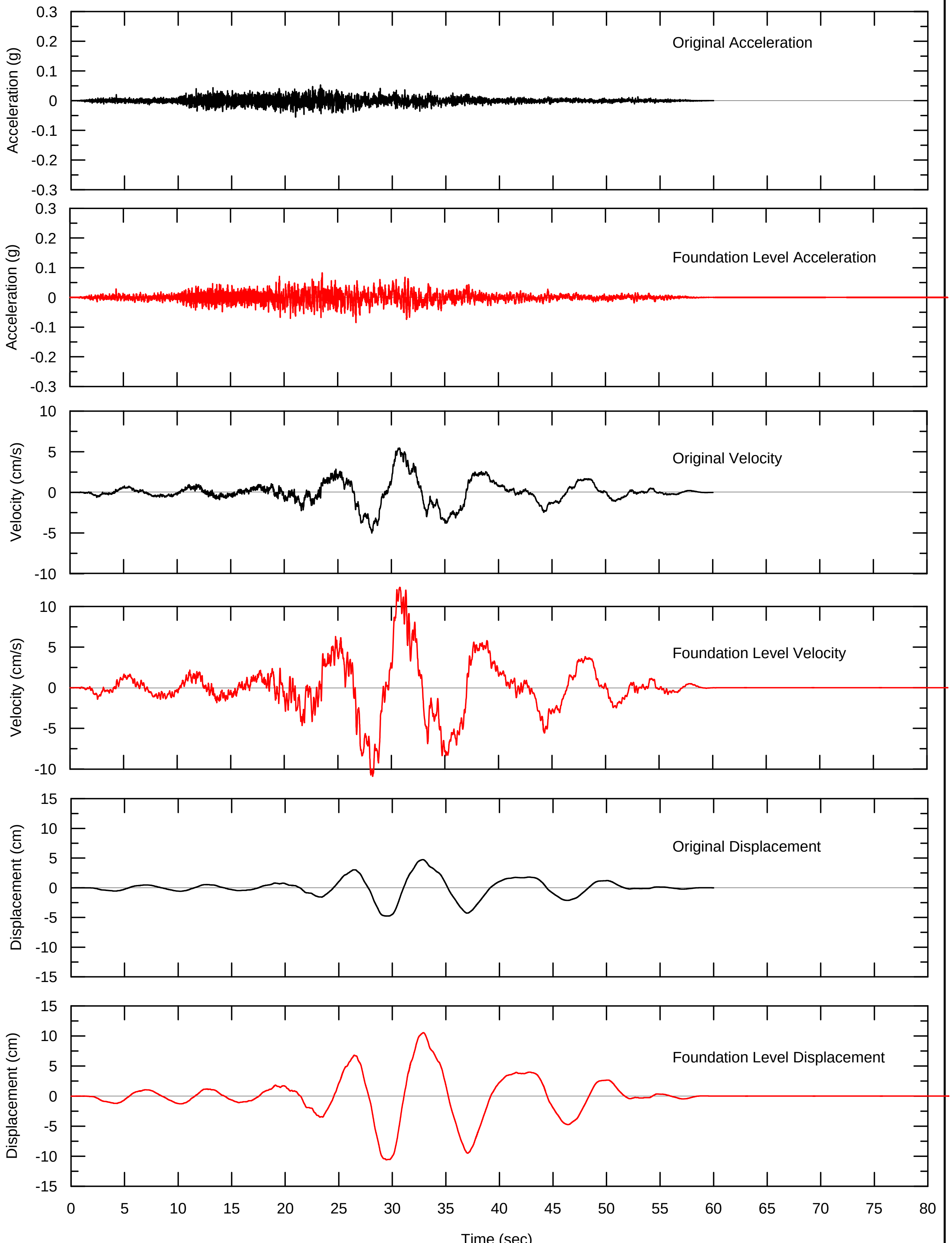

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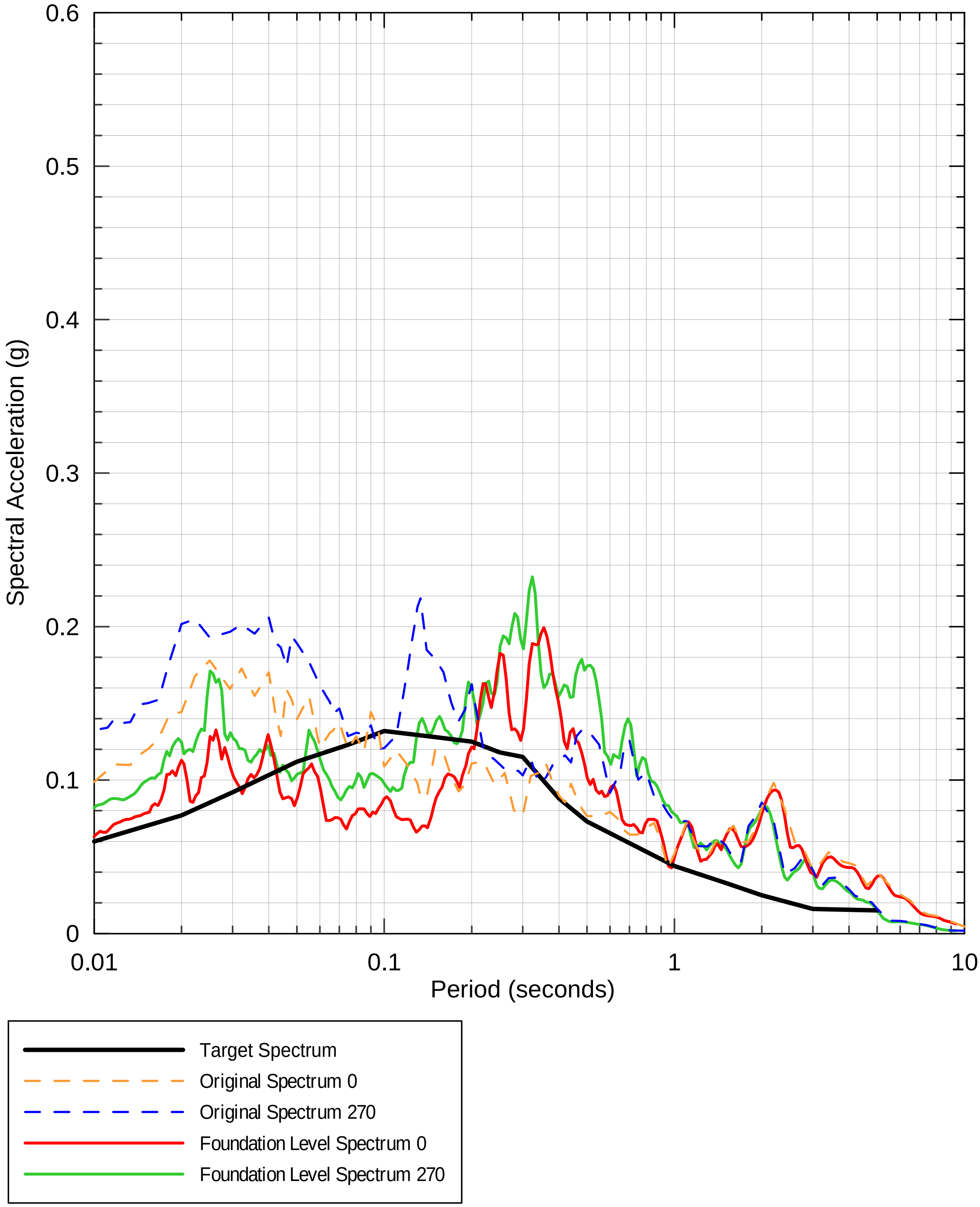
1999, Duzce, Turkey, Sakarya, 180 Foundation Level Motion for 2,475-Year RP GMHGA,Washington Monument	By: DG	Date: 4/23/2012	Project No. OD12162670
	amec		Figure **C-8c**



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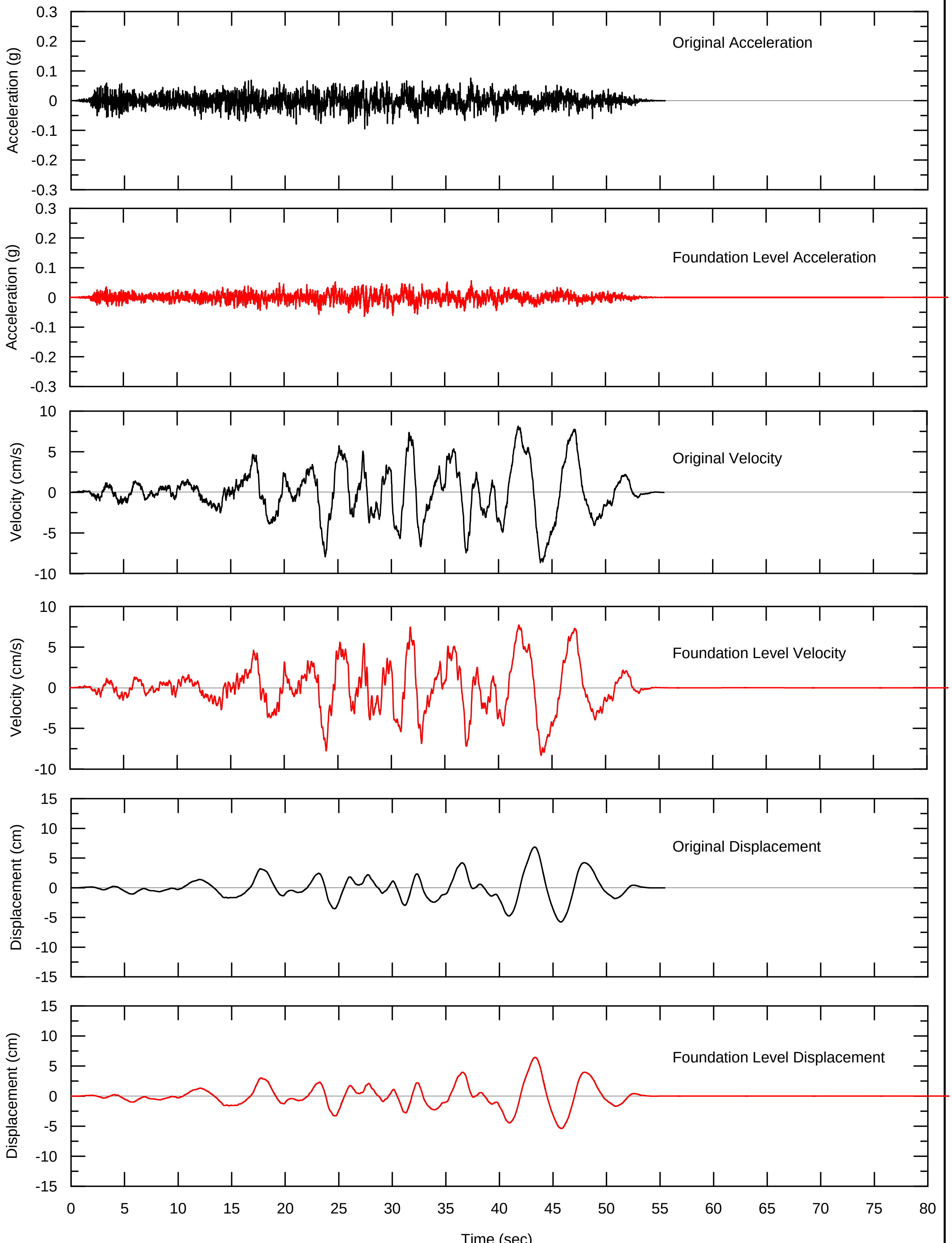
Horizontal Response Spectra
1992, Landers, Villa Park - Serrano Ave
Foundation Level Motion for 2,475-Year RP
Ground Motion Hazard and Geotechnical Assessment
Washington Monument
Washington, District of Colombia

By: DG	Date: 4/23/2012	Project No. OD12162670
amec		Figure **C-9a**



1992, Landers, Villa Park - Serrano Ave, 0 Foundation Level Motion for 2,475-Year RP GMHGA,Washington Monument	By: DG	Date: 4/23/2012	Project No. OD12162670
	amec		Figure **C-9b**

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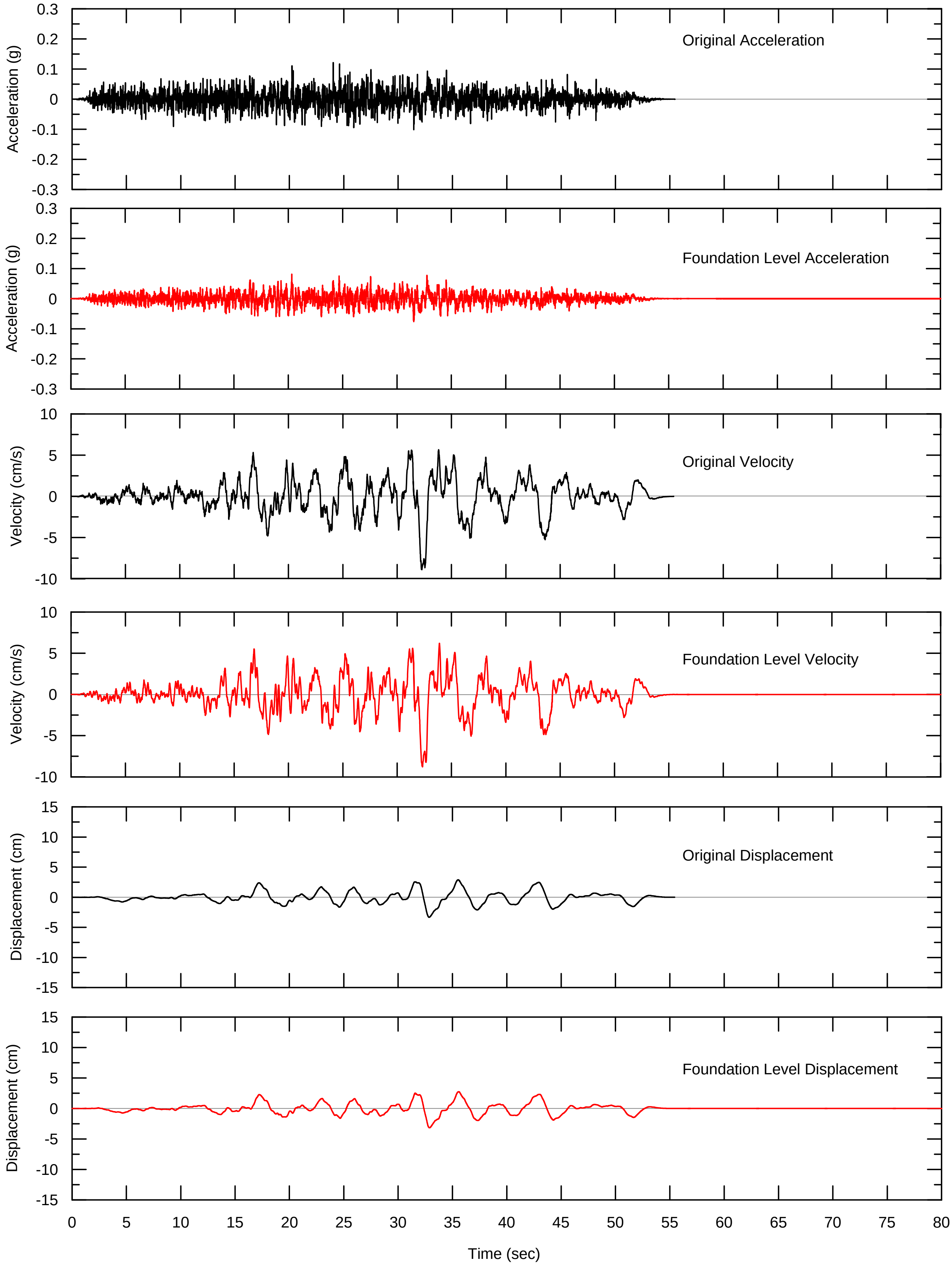
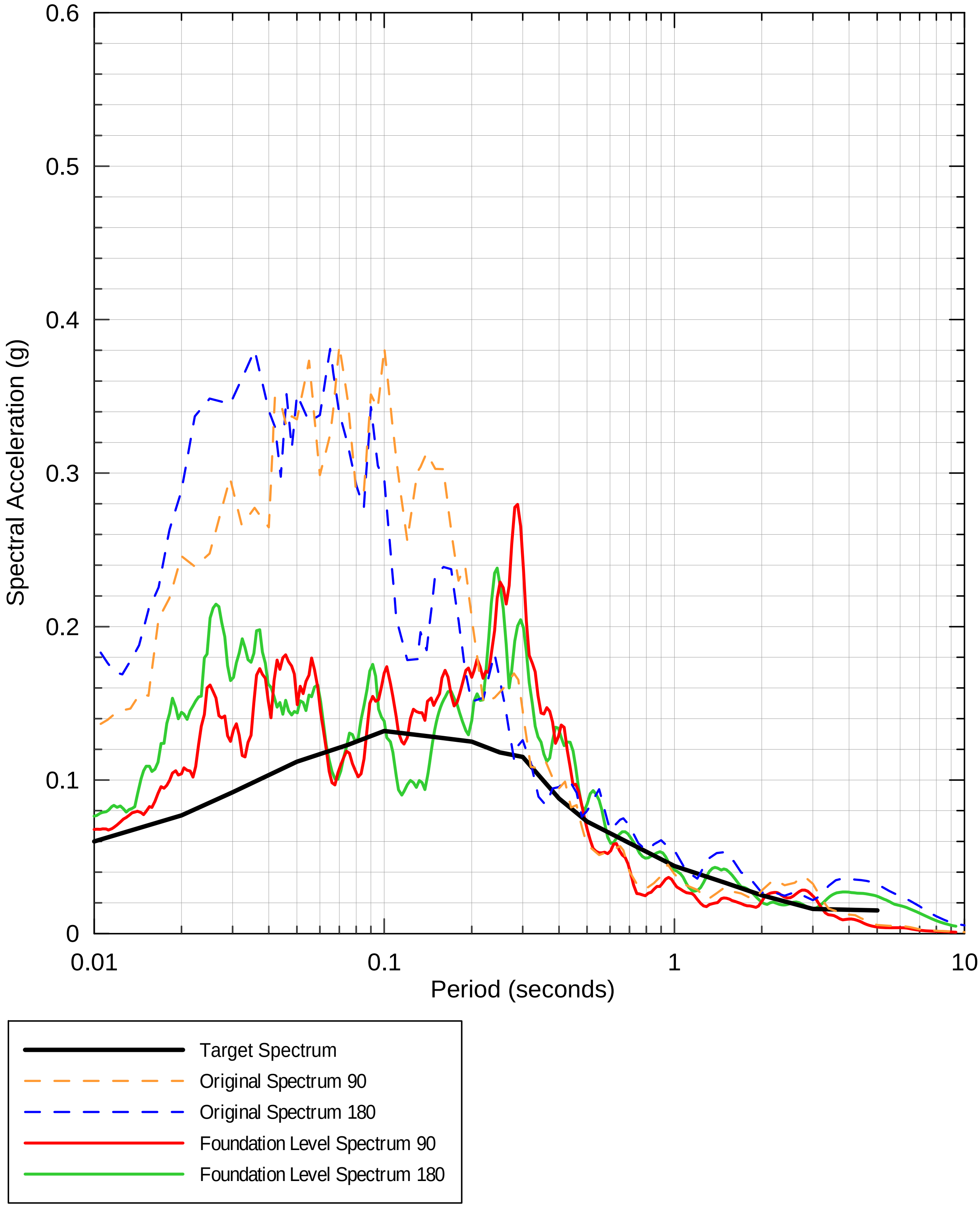


1992, Landers, Villa Park - Serrano Ave, 270 Foundation Level Motion for 2,475-Year RP GMHGA,Washington Monument	By: DG	Date: 4/23/2012	Project No. OD12162670
	amec		Figure **C-9c**



Horizontal Response Spectra
1999, Kocaeli, Turkey, Mecidiyekoy
Foundation Level Motion for 2,475-Year RP
Ground Motion Hazard and Geotechnical Assessment
Washington Monument
Washington, District of Colombia

By: DG	Date: 4/23/2012	Project No. OD12162670
amec		Figure **C-10a**

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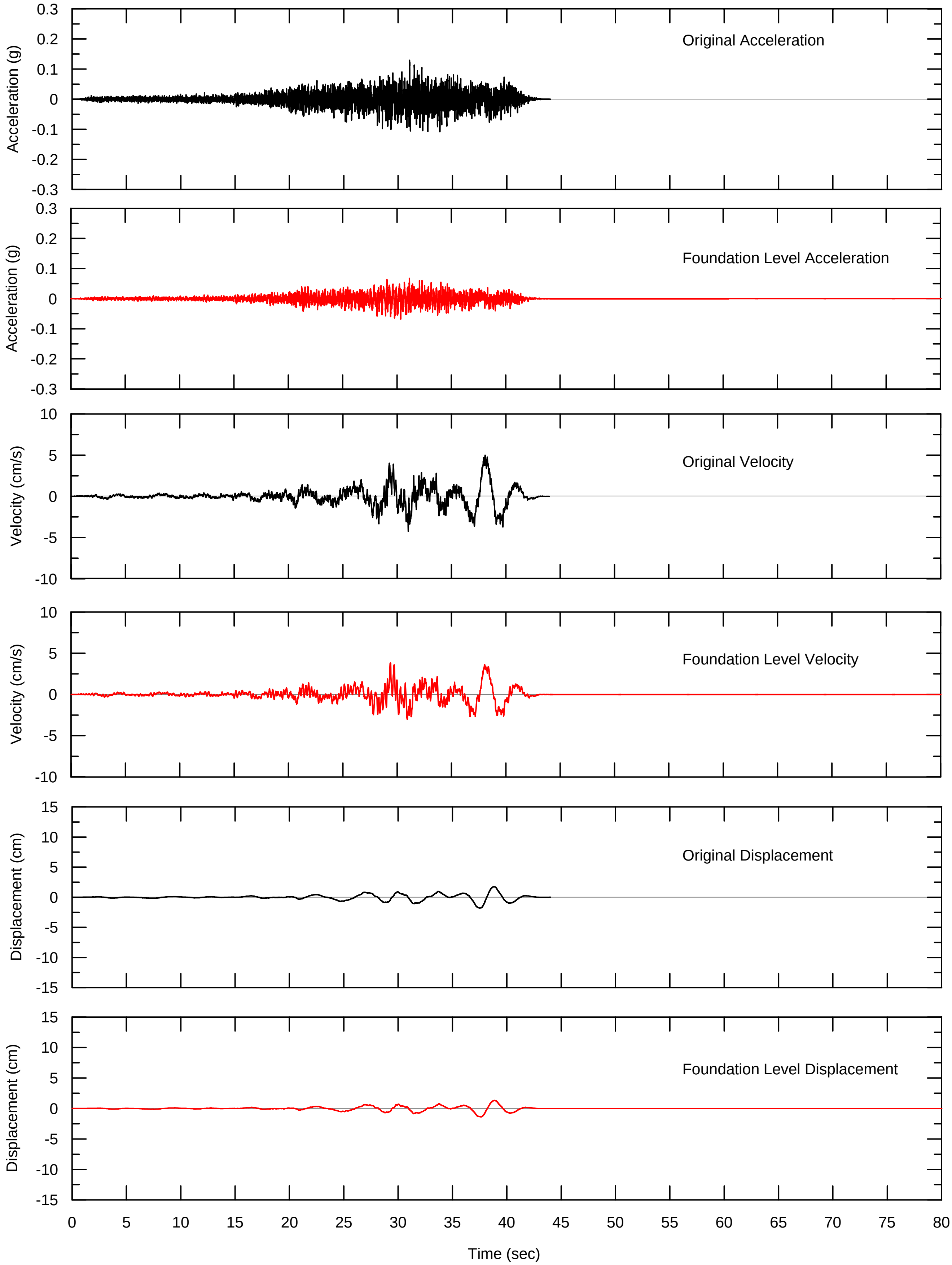

1999, Kocaeli, Turkey, Mecidiyekoy, 0 Foundation Level Motion for 2,475-Year RP GMHGA,Washington Monument	By: DG	Date: 4/23/2012	Project No. OD12162670
	amec		Figure **C-10b**

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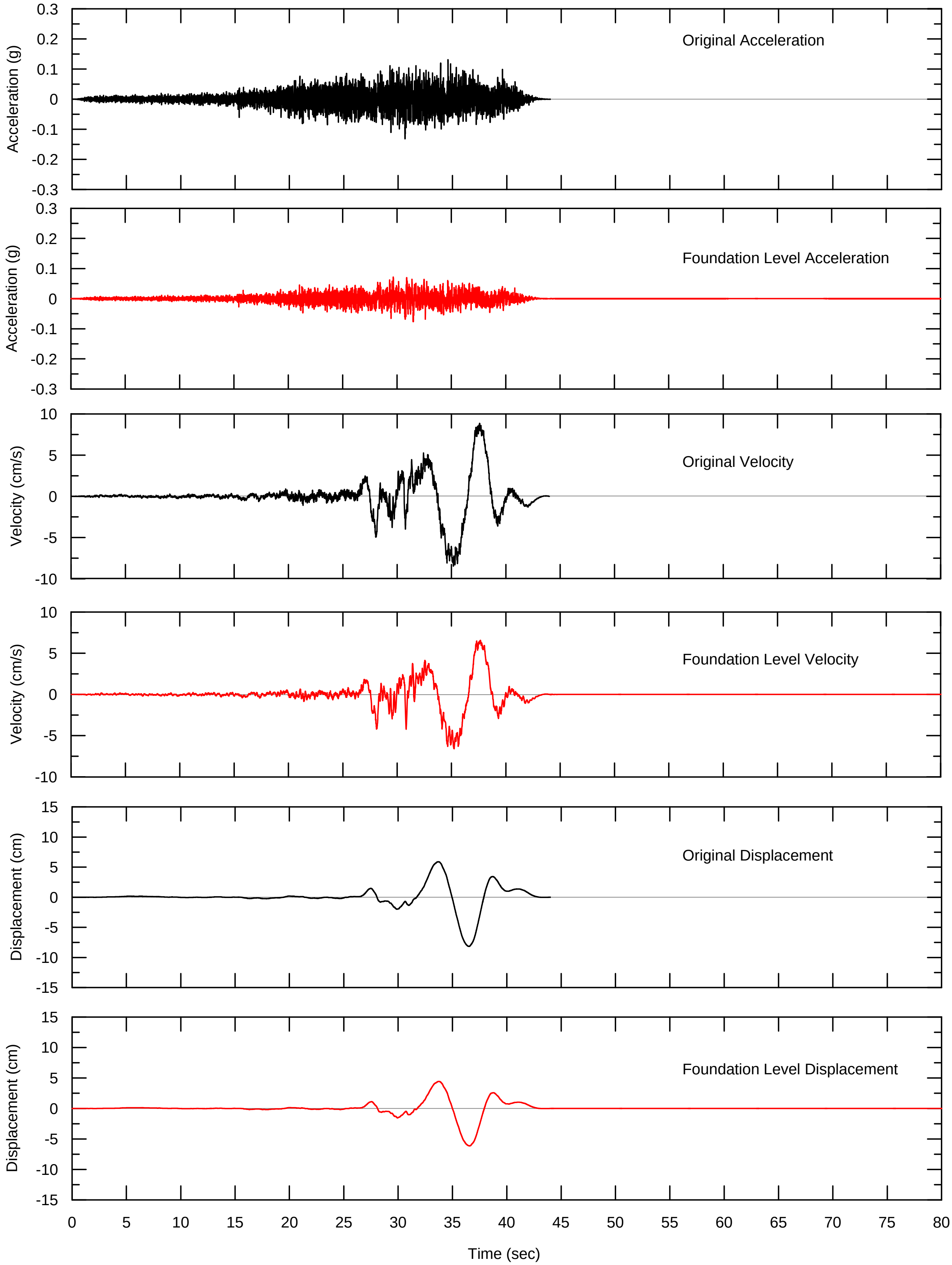

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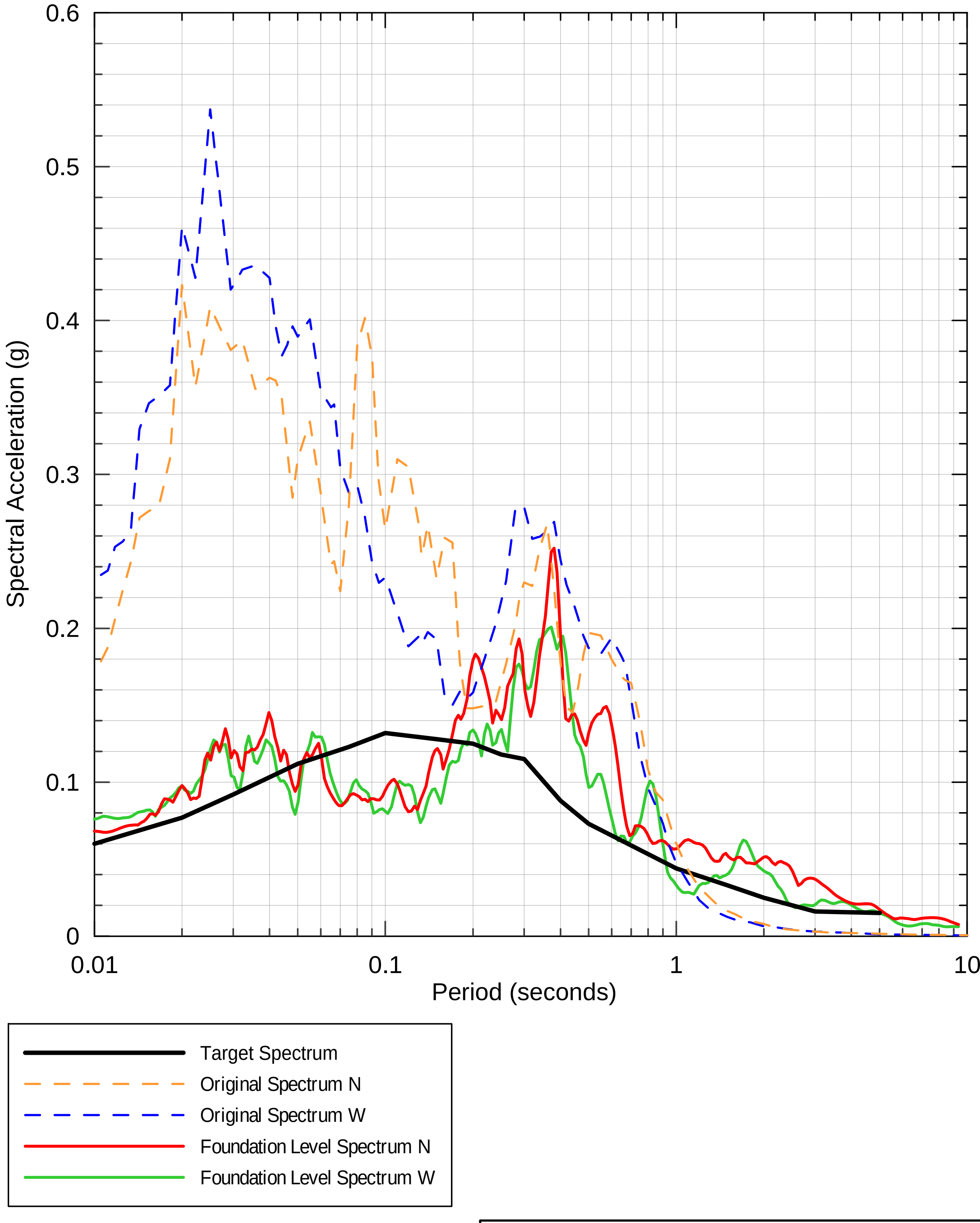
1999, Kocaeli, Turkey, Mecidiyekoy, 90
Foundation Level Motion for 2,475-Year RP
GMHGA,Washington Monument

By: DG	Date: 4/23/2012	Project No. OD12162670
	amec	Figure **C-10c**



Horizontal Response Spectra
1999, Chi-Chi, Taiwan, HWA023
Foundation Level Motion for 2,475-Year RP
Ground Motion Hazard and Geotechnical Assessment
Washington Monument
Washington, District of Colombia

By: DG	Date: 4/23/2012	Project No. OD12162670
amec		Figure **C-11a**

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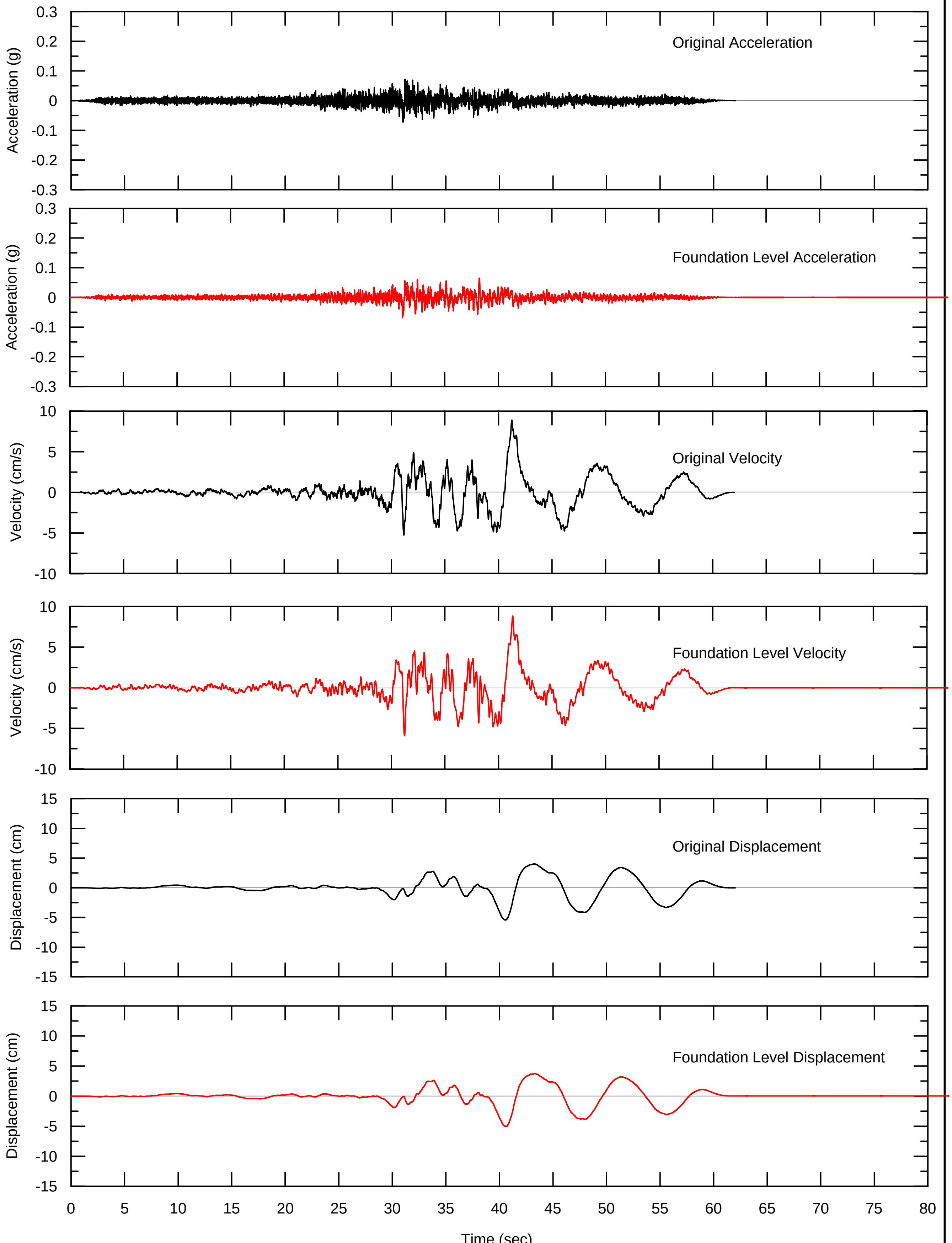

1999, Chi-Chi, Taiwan, HWA023, N
Foundation Level Motion for 2,475-Year RP
GMHGA,Washington Monument

By: DG

Date: 4/23/2012

Project No. OD12162670

amec

Figure **C-11b**

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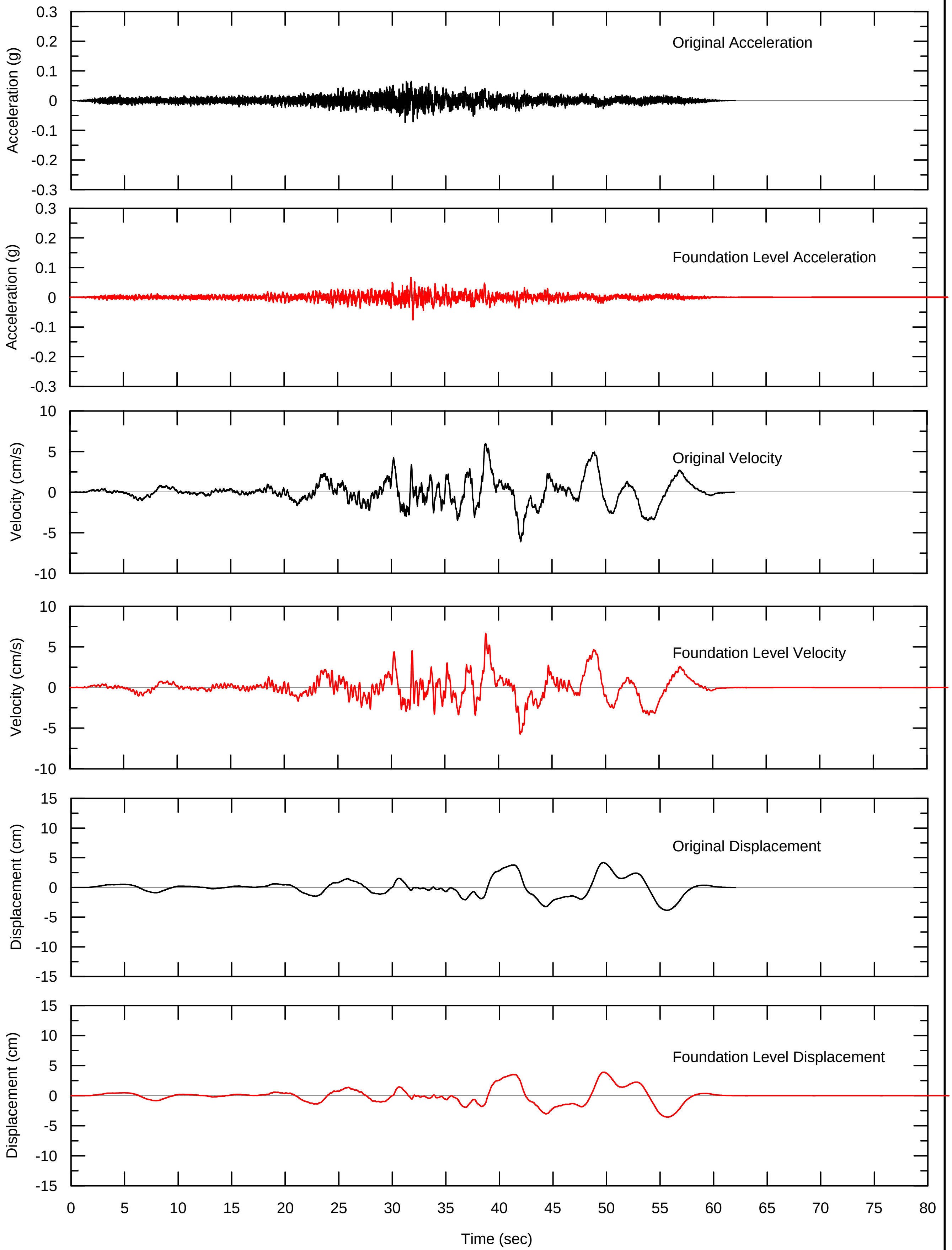

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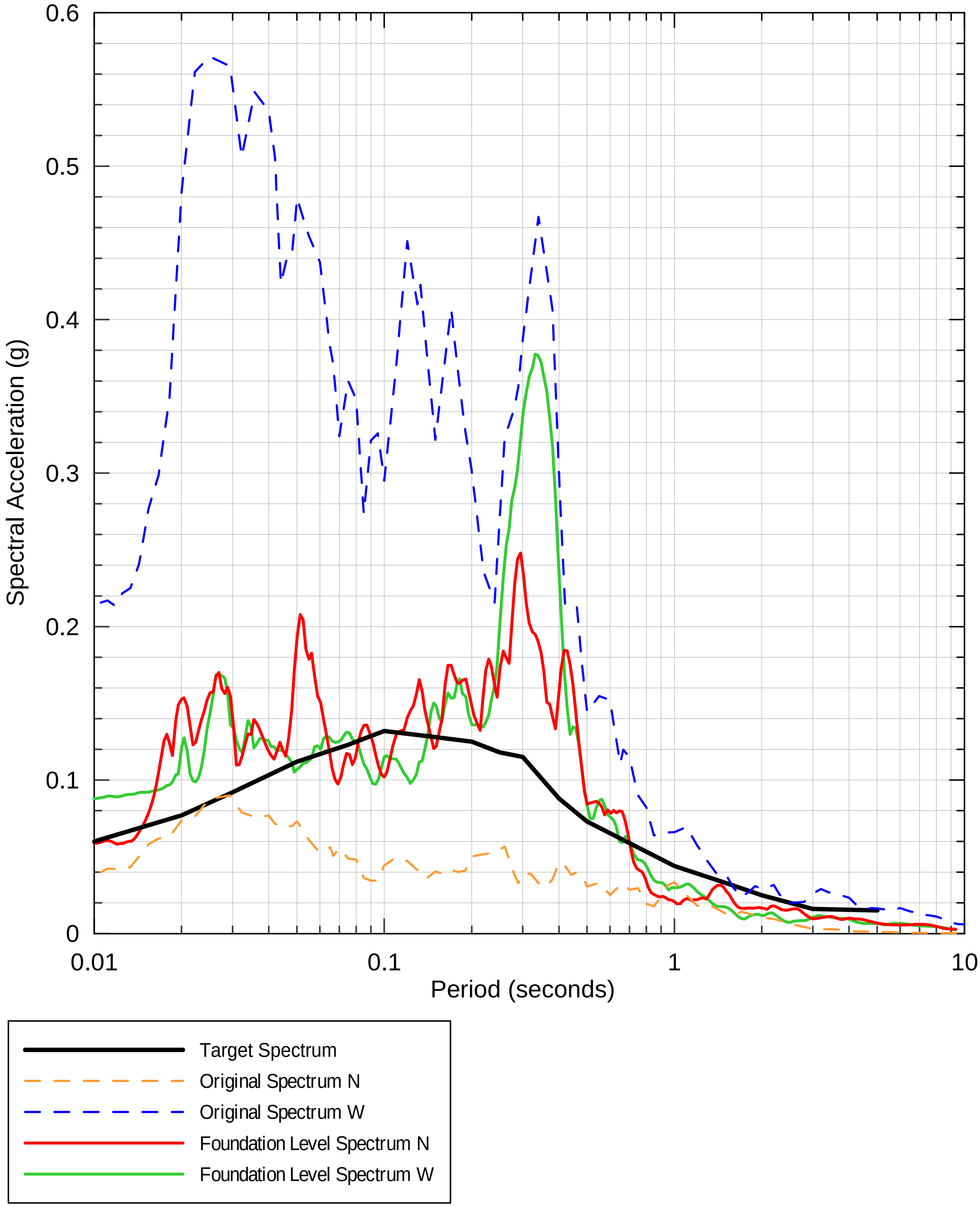
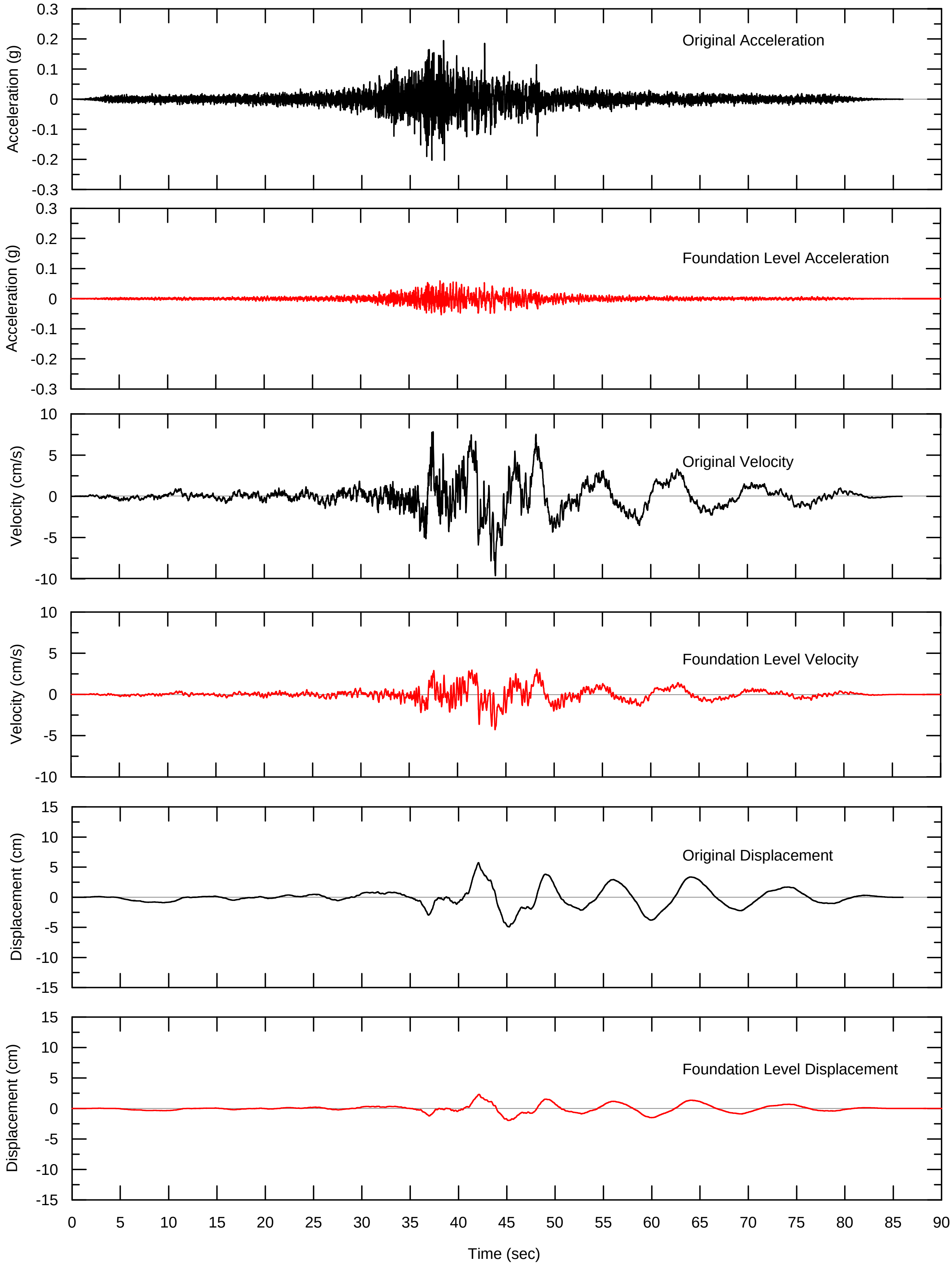
1999, Chi-Chi, Taiwan, HWA023, W Foundation Level Motion for 2,475-Year RP GMHGA,Washington Monument	By: DG	Date: 4/23/2012	Project No. OD12162670
	amec		Figure **C-11c**



Horizontal Response Spectra
1999, Chi-Chi, Taiwan, HWA056
Foundation Level Motion for 2,475-Year RP
Ground Motion Hazard and Geotechnical Assessment
Washington Monument
Washington, District of Colombia

By: DG	Date: 4/23/2012	Project No. OD12162670
amec		Figure **C-12a**



1999, Chi-Chi, Taiwan, HWA056, N
Foundation Level Motion for 2,475-Year RP
GMHGA,Washington Monument

By: DG | Date: 4/23/2012 | Project No. OD12162670

amec

Figure **C-12b**

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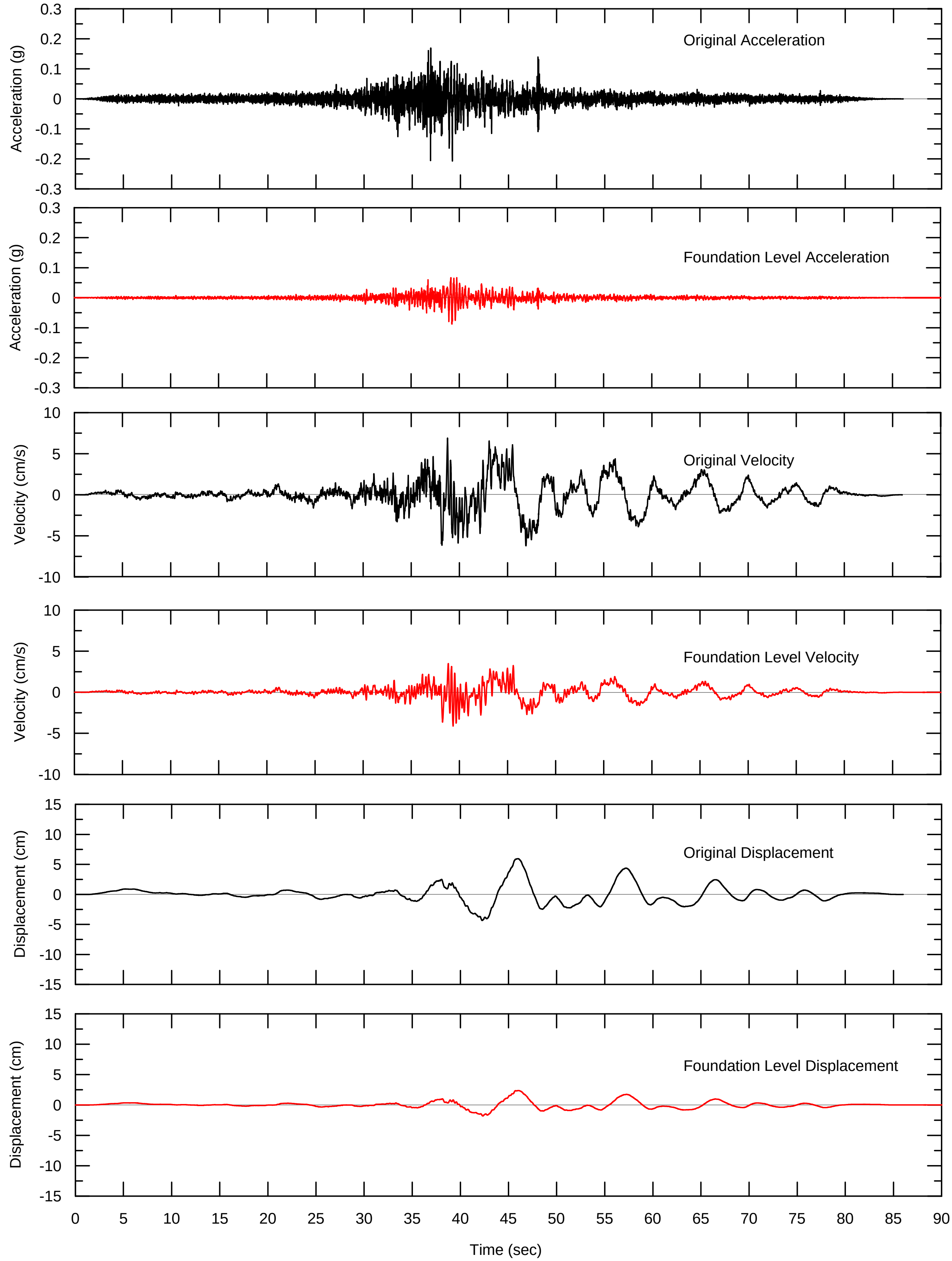

1999, Chi-Chi, Taiwan, HWA056, W Foundation Level Motion for 2,475-Year RP GMHGA,Washington Monument	By: DG	Date: 4/23/2012	Project No. OD12162670
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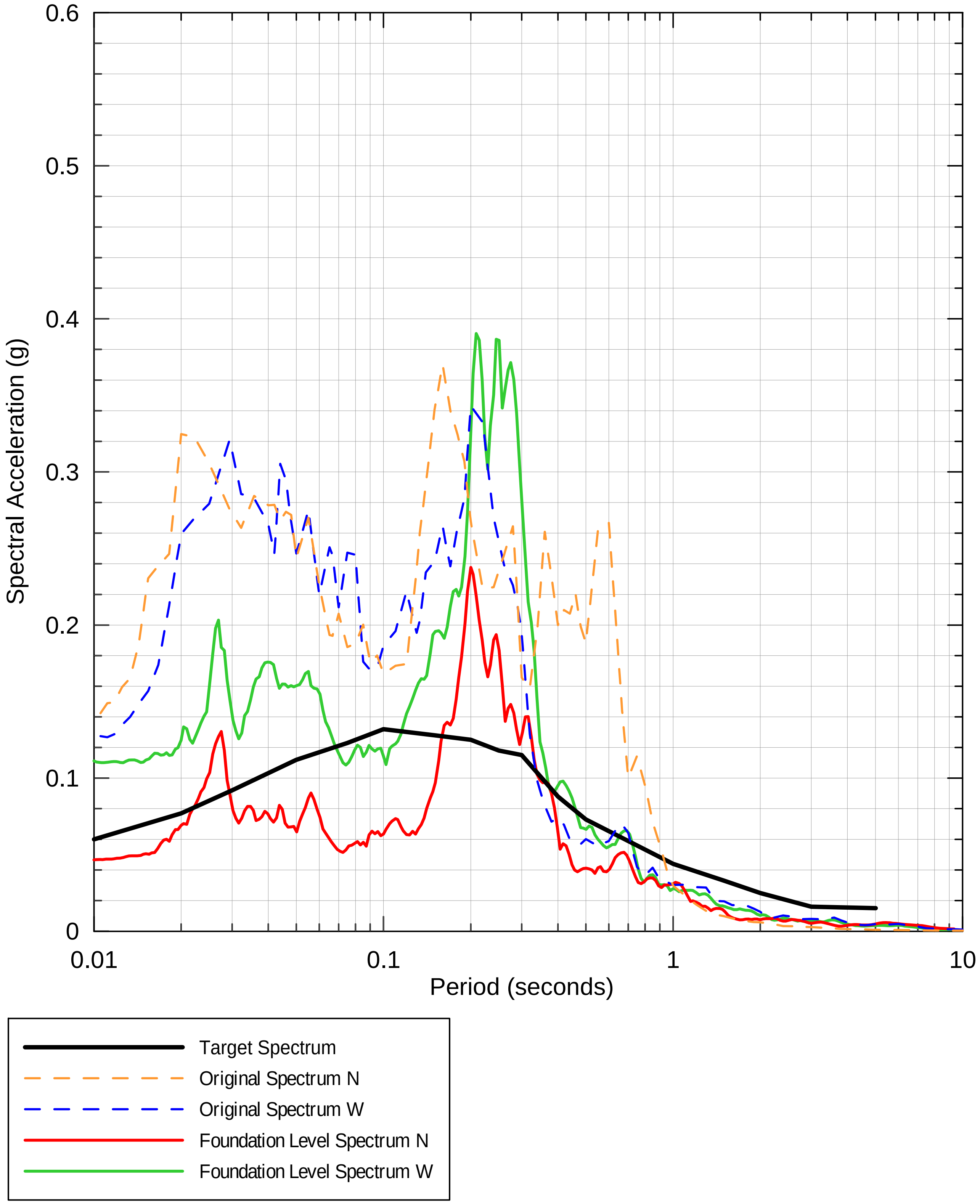

Horizontal Response Spectra
1999, Chi-Chi, Taiwan, KAU078
Foundation Level Motion for 2,475-Year RP
Ground Motion Hazard and Geotechnical Assessment
Washington Monument
Washington, District of Colombia

By: DG	Date: 4/23/2012	Project No. OD12162670
amec		Figure **C-13a**

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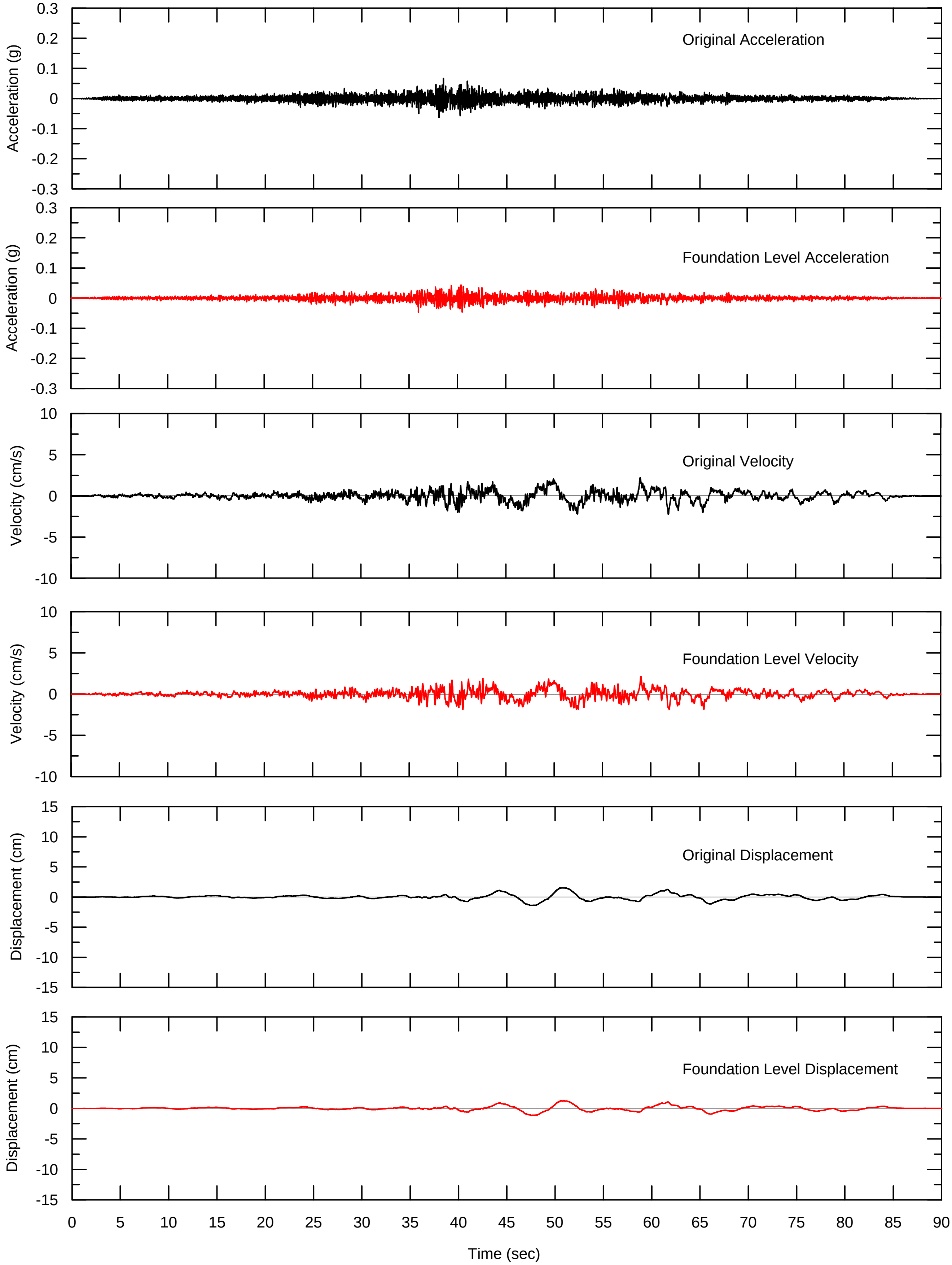

1999, Chi-Chi, Taiwan, KAU078, N
Foundation Level Motion for 2,475-Year RP
GMHGA,Washington Monument

By: DG | Date: 4/23/2012 | Project No. OD12162670

amec

Figure **C-13b**

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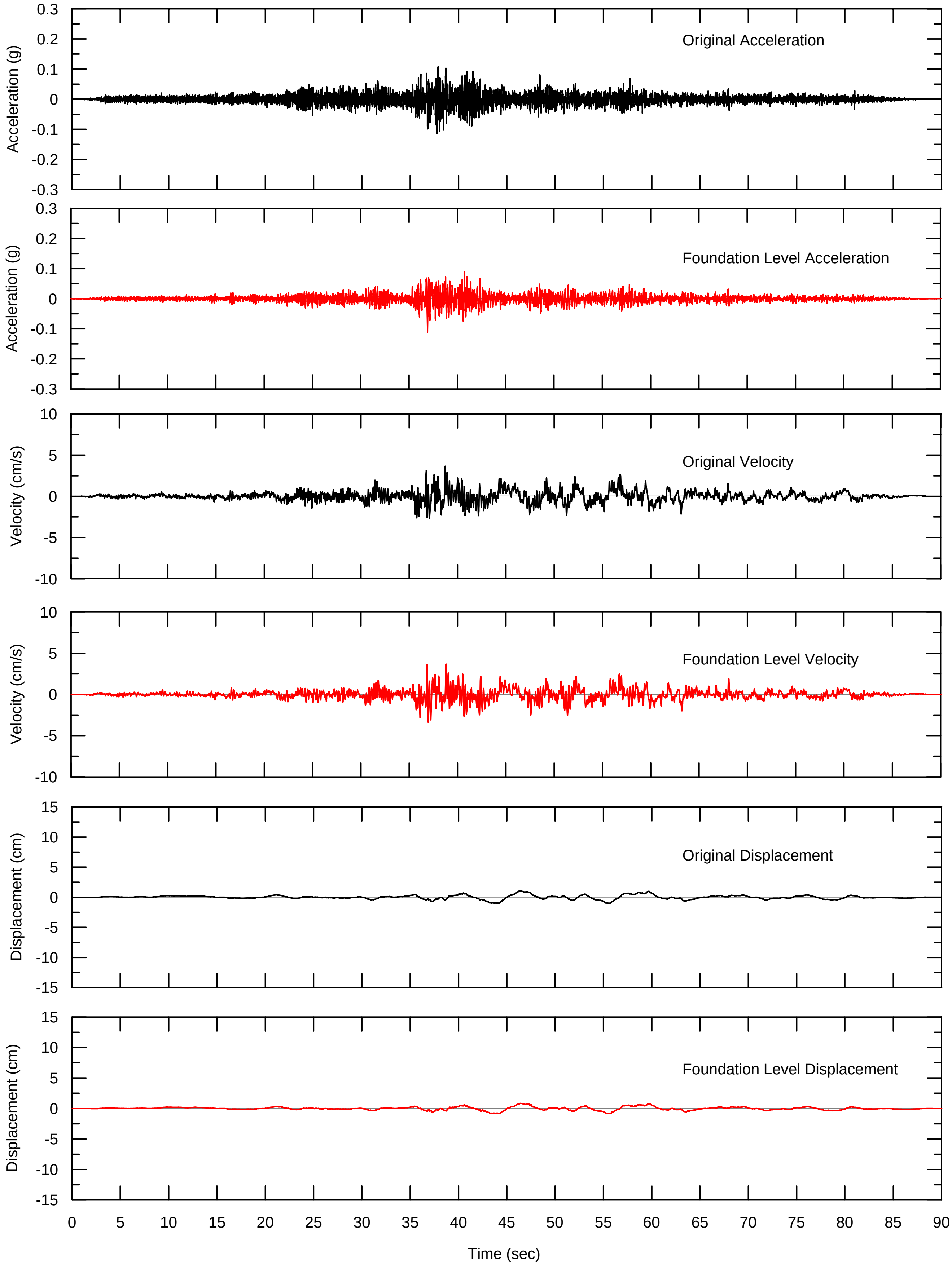

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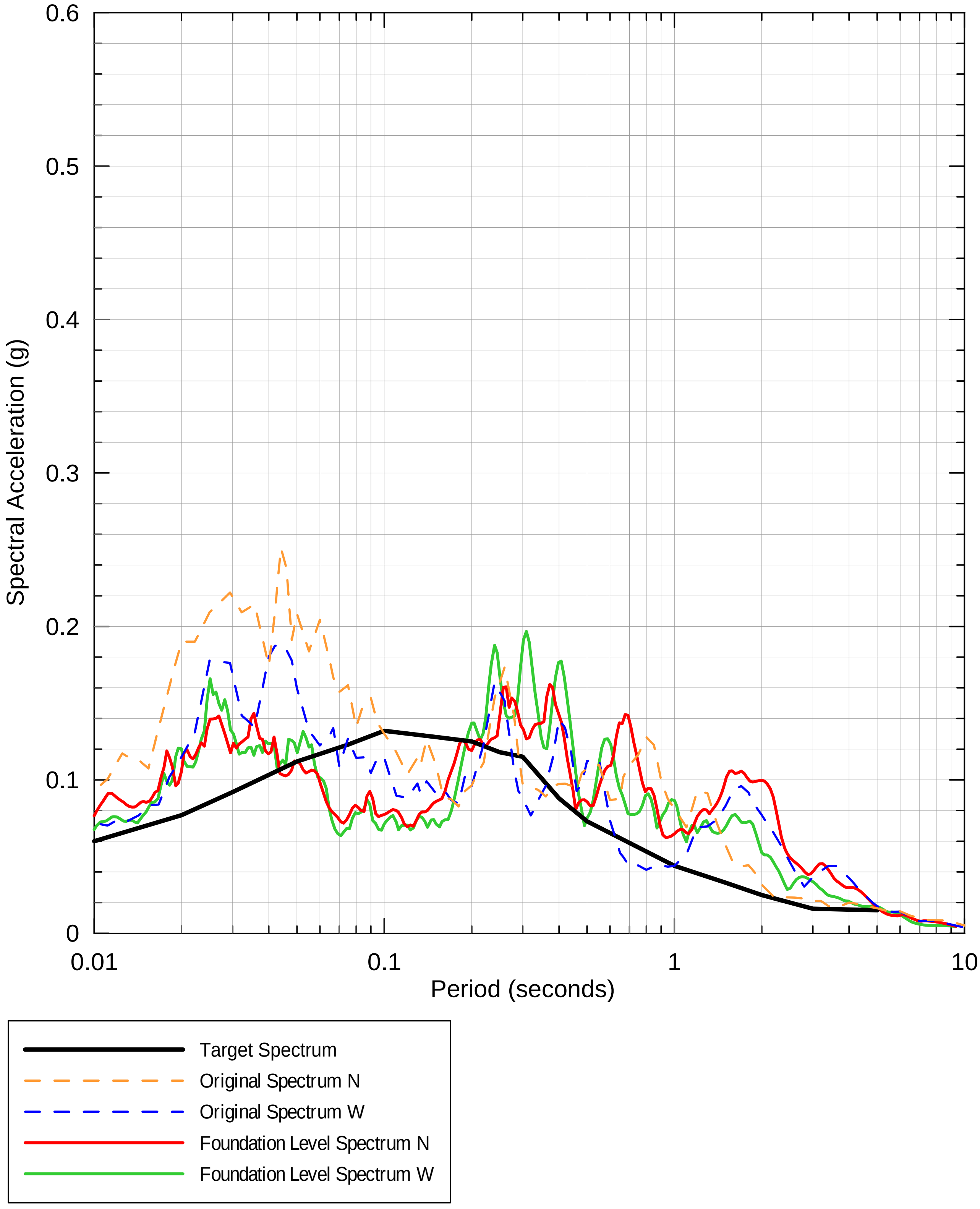

Horizontal Response Spectra
1999, Chi-Chi, Taiwan, TAP060
Foundation Level Motion for 2,475-Year RP
Ground Motion Hazard and Geotechnical Assessment
Washington Monument
Washington, District of Colombia

By: DG	Date: 4/23/2012	Project No. OD12162670
amec		Figure **C-14a**

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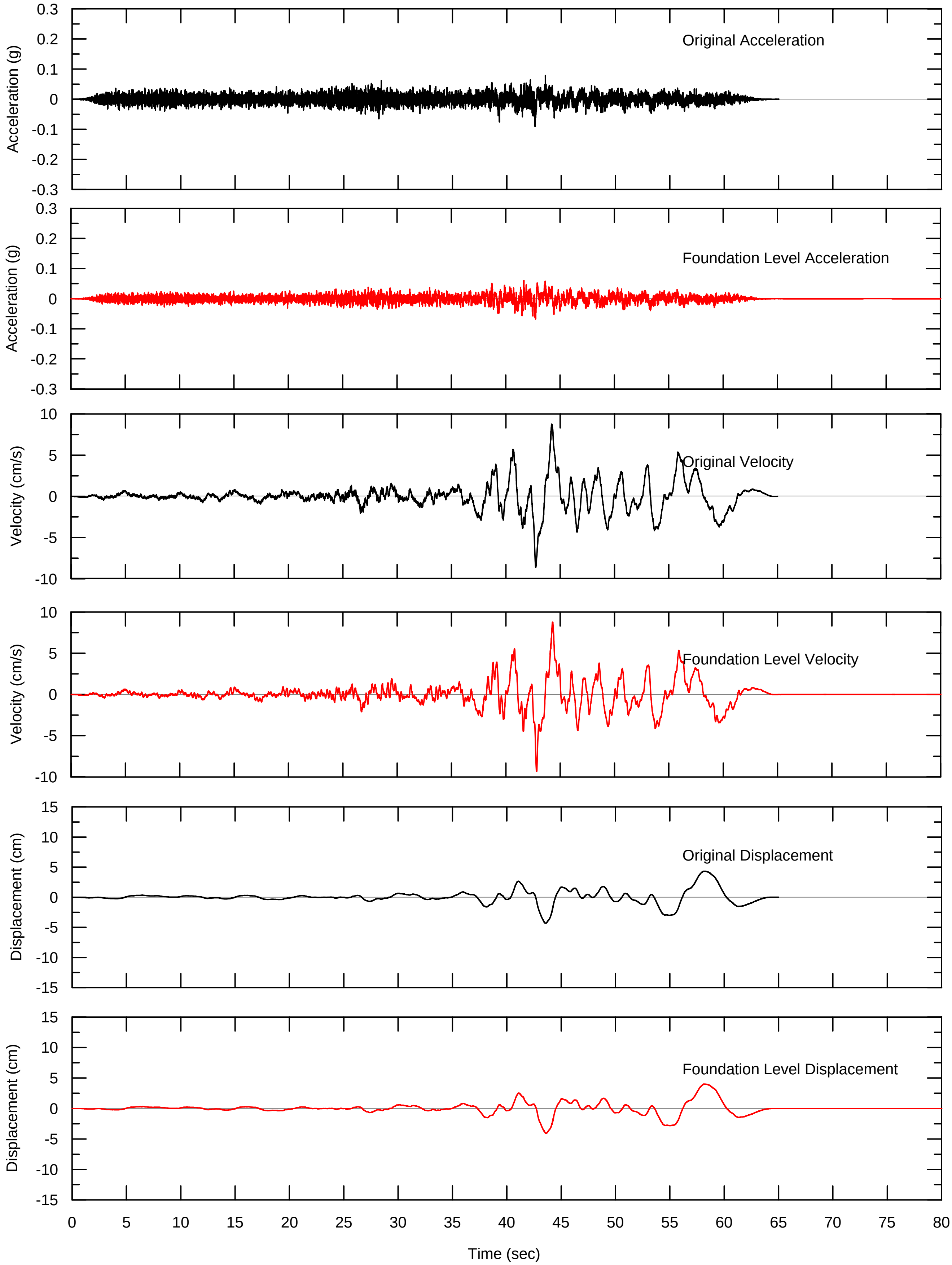

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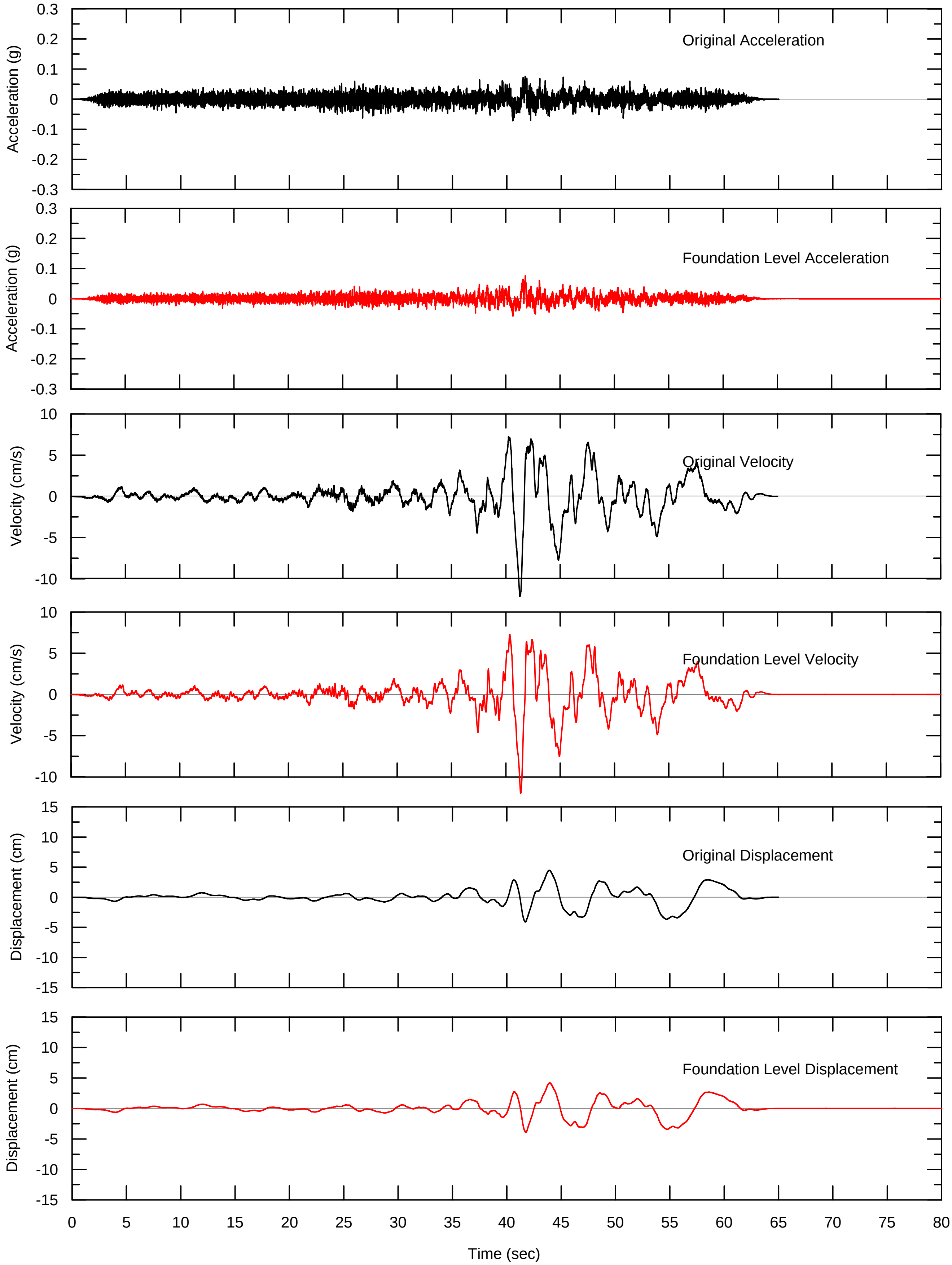
1999, Chi-Chi, Taiwan, TAP060, N Foundation Level Motion for 2,475-Year RP GMHGA,Washington Monument	By: DG	Date: 4/23/2012	Project No. OD12162670
	amec		Figure **C-14b**



1999, Chi-Chi, Taiwan, TAP060, W Foundation Level Motion for 2,475-Year RP GMHGA,Washington Monument	By: DG	Date: 4/23/2012	Project No. OD12162670
	amec		Figure C-14c

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