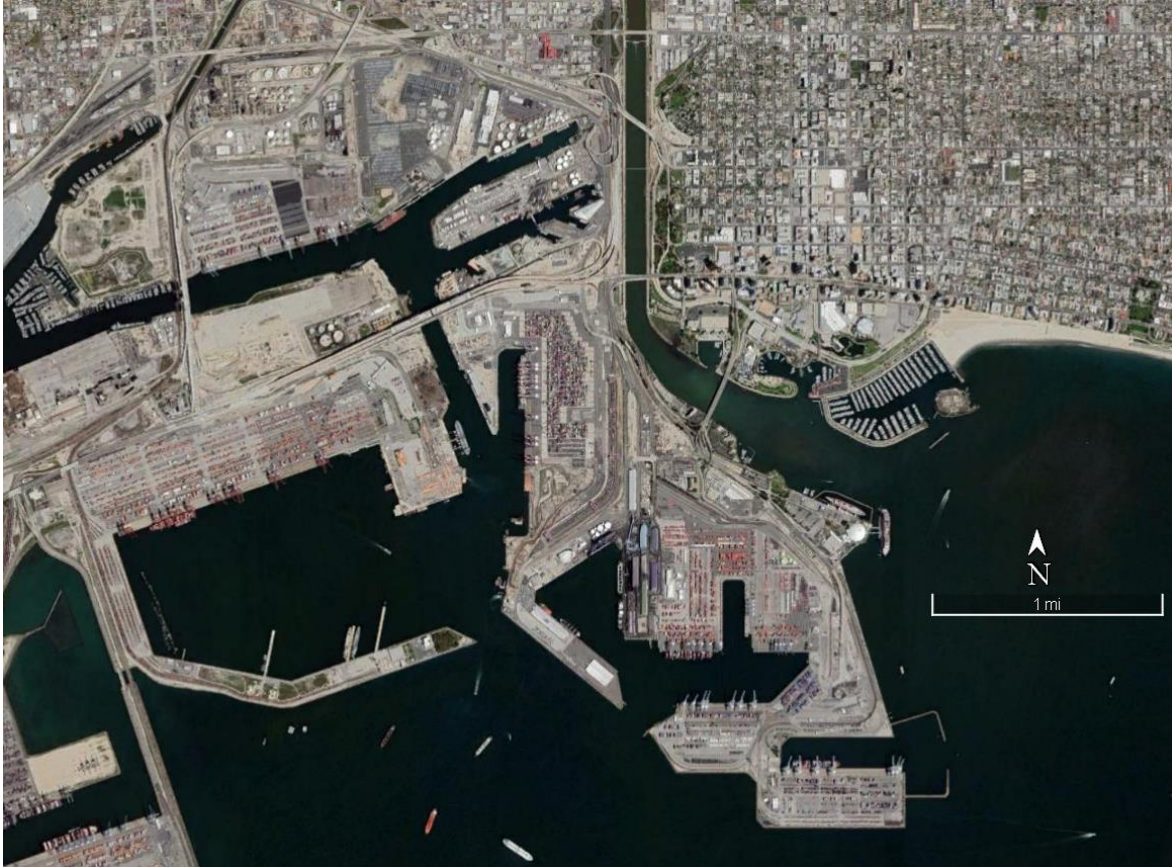


PORT-WIDE GROUND MOTION STUDY UPDATE PORT OF LONG BEACH, CALIFORNIA

ADDENDUM NO. 1

UPDATES TO CODE-BASED DESIGN EARTHQUAKE BASED ON CBC 2025



Prepared For:



The Port of Long Beach
415 West Ocean Blvd.
Long Beach, CA 90802

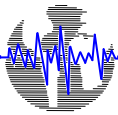
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EMI Project No. 23-150-2

April 17, 2026



Earth Mechanics, Inc.

Geotechnical & Earthquake Engineering

April 17, 2026

EMI Project No. 23-150-2

The Port of Long Beach
415 West Ocean Blvd.
Long Beach, CA 90802

Attention: Mr. Joel Aguilar, S.E.
Assistant Director of Engineering Design

Subject: **Addendum No. 1 to the 2020 Port-Wide Ground Motion Study Update Report,
Updates to Code-Based Design Earthquake (DE) Based on CBC 2025
Port of Long Beach, California**

Dear Mr. Aguilar,

Attached please find Addendum No. 1 to the Port-Wide Ground Motion Study Update Report for the Port of Long Beach, California. The previous port-wide ground motion study, prepared by Earth Mechanics, Inc. in 2020, adopted the 2019 California Building Code (CBC), which used ASCE 7-16 for development of the code-based Design Earthquake (DE) response spectrum. The 2025 CBC is based on ASCE 7-22, which has introduced significant changes to the procedures for developing seismic design parameters, necessitating updates to the DE response spectrum.

This report contains the methodology and findings of our study to update the CBC-based DE seismic parameters and ground motions based on the 2025 CBC and ASCE 7-22 Standard.

The ground motion recommendations presented in this addendum supersede the CBC-based DE recommendations provided in all previous POLB port-wide ground motion studies.

On behalf of the entire project team, we appreciate the opportunity to work with you on this project. If you have any questions or comments on this report, please do not hesitate to call us.

Sincerely,

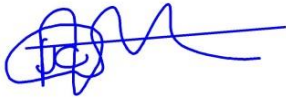
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Appendix A	Probabilistic Seismic Hazard Analysis (PSHA)
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1.0 INTRODUCTION

1.1 Background

The Port of Long Beach (POLB) commissioned a port-wide ground motion (PWGM) study in 2004 to develop consistent earthquake ground motion recommendations for design of structures within the entire Port area. The initial PWGM study was performed by Earth Mechanics, Inc. (EMI) and at the conclusion of the study in August 2006, EMI issued a PWGM study report (EMI, 2006). The report included recommendations for two levels of earthquakes: Operating Level Earthquake (OLE) and Contingency Level Earthquake (CLE). The CLE corresponds to the design earthquake defined in the 2001 California Building Code (CBC, 2001). The PWGM study report was referenced in the first version of the Wharf Design Criteria (WDC) document that was prepared by the Port of Long Beach that outlines the guidelines, recommendations, and requirements for design of new wharves at the POLB (POLB, 2007).

Since completion of the PWGM study report, significant advancements in ground motion predictions have been made through the first NGA Project in 2008 and the NGA-West2 Project, sponsored by the Pacific Earthquake Engineering Research Center (PEER) that was completed in 2014 (Bozorgnia, et al., 2014; EERI, 2014). Similarly, significant advancements have also been made in the understanding of the California earthquake rupture mechanisms through the project sponsored jointly by the United States Geological Survey (USGS), California Geological Survey (CGS), and the Southern California Earthquake Center (SCEC) and the Working Group of California Earthquake Probabilities completed a report titled “Uniform California Earthquake Rupture Forecast, Version 3 (UCERF3)–The Time Independent Model” (USGS, 2013). The study also included the newly characterized Wilmington Blind-Thrust Fault (Wolfe et al., 2019) that has not been included in the USGS model. Furthermore, the 2019 CBC (effective January 1, 2020) incorporated the recommendations from ASCE 7 (ASCE, 2016), that require revisions to the DE recommendations. EMI updated the PWGM study incorporating these changes (EMI, 2020).

1.2 Project Description

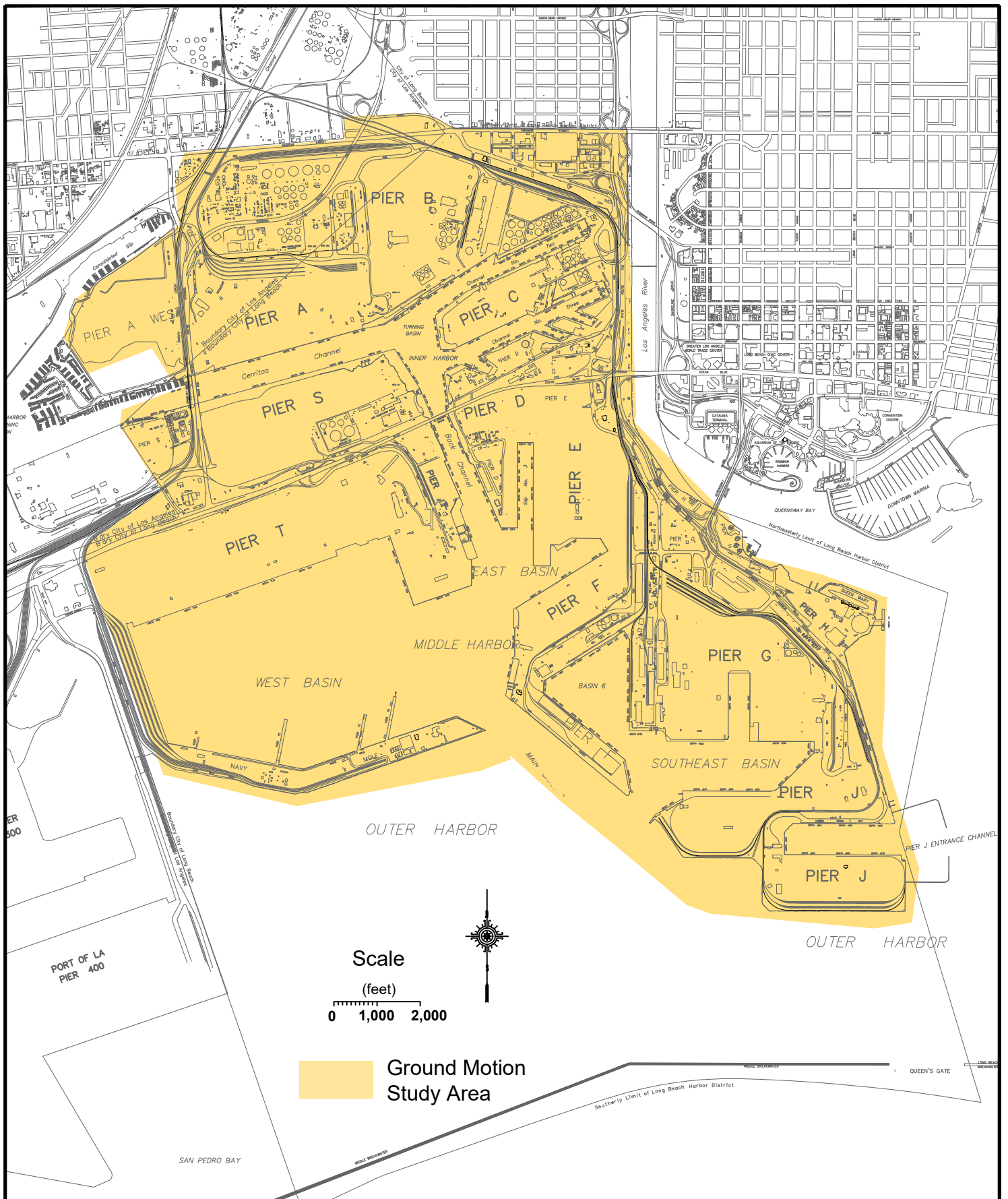
Figure 1-1 identifies the project limits covered by this study. The 2025 California Building Code (CBC), effective January 1, 2026, incorporates the recommendations of the latest ASCE 7 standard, ASCE 7-22 (ASCE/SEI 7, 2022). Compared with ASCE 7-16, the procedures for developing seismic design parameters in ASCE 7-22 have changed substantially, necessitating updates to the Design Earthquake (DE) recommendations presented in the 2020 PWGM study (EMI, 2020).

This project aims to revise the DE seismic parameters to ensure compliance with the ASCE 7-22 requirements.

1.3 Scope of Work

The scope of the study includes the following tasks:

- ❖ Collect and review available geologic and geotechnical documents to develop soil profiles underlain by Site Class C ground per Chapter 21 of ASCE 7-22.
- ❖ Perform Probabilistic Seismic Hazard Analysis (PSHA) per the Uniform California Earthquake Rupture Forecast, Version 3 (UCERF3) (USGS, 2013) including the newly characterized Wilmington Fault (Wolfe et al., 2019) and the latest USGS seismic hazard models and develop risk-targeted response spectrum (MCE_R) for the reference firm ground defined as Site Class C, $V_{s,30}=1,500$ ft/s based on ASCE 7-22-Chapter 21.
- ❖ Develop a suite of seven (7) sets of acceleration-time histories which are spectrum-matched to the reference firm ground MCE_R .
- ❖ Develop lower-bound, upper-bound, and liquefied-condition soil profiles to characterize existing subsurface soil conditions within the POLB.
- ❖ Perform one-dimensional site response analyses for various soil profiles developed above. Perform sensitivity studies to incorporate uncertainties in ground conditions.
- ❖ Develop DE response spectrum at the ground surface for both unimproved and improved (firm) ground based on ASCE 7-22-Chapter 21.
- ❖ Develop vertical component DE response spectrum for both unimproved and improved ground based on ASCE 7-22- Chapter 11.
- ❖ Develop a suite of seven (7) sets of spectrum-compatible acceleration-time histories for DE for unimproved and improved ground conditions.
- ❖ Develop design seismic parameters for geotechnical evaluations in accordance with ASCE 7-22.
- ❖ Perform Newmark displacement analyses for DE, and maximum considered earthquake geometric mean (MCE_G).
- ❖ Document the results and recommendations in Addendum No. 1 to the 2020 Port-Wide Ground Motion Study Report.



Earth Mechanics, Inc.
Geotechnical and Earthquake Engineering

**Addendum No. 1 to the 2020 Port-Wide Ground Motion Study Update,
Port of Long Beach, California**

Site Location Map at POLB

Figure 1-1

Project No. 23-150-2

Date: April 2026

2.0 Characterization of Subsurface Conditions Per ASCE 7-22

In the 2020 PWGM study (EMI, 2020), the primary source of information on ground conditions at the POLB consisted of previously completed, project-specific reports provided by the POLB. These sources primarily included geotechnical investigations conducted at berths, piers, and other facilities. Subsurface data from these reports were typically derived from boring investigations, with Standard Penetration Test (SPT) data generally obtained at 5-foot intervals, as well as Cone Penetration Test (CPT) soundings. Findings suggested a demarcation of the POLB into four areas denoted as Zones I, II, III and IV in which similar soil profiles were apparent. It should be noted that during the 2020 POLB PWGM study (EMI, 2020), sufficient soil data were not available for the far northeastern corner of the POLB jurisdictional limits, i.e., northeast of Pier B. This area was designated as “TBD” and the findings of the 2020 PWGM study were therefore not applicable to the TBD area. However, with recent developments at Pier B, sufficient soil data, including soil borings and CPTs extending to depths of up to 100 ft, are now available to evaluate subsurface conditions within the TBD area. These data are documented in the geotechnical design reports prepared by HDR (2025a, b, c, d, e). Based on the available information, subsurface conditions are generally consistent with those encountered in Soil Zone II. The approximate extents of Soil Zones I thru IV are shown in Figure 2-1.

The four idealized soil profiles and shear wave velocity profiles corresponding to each zone that were considered in the 2020 PWGM study are shown in Figure 2-2.

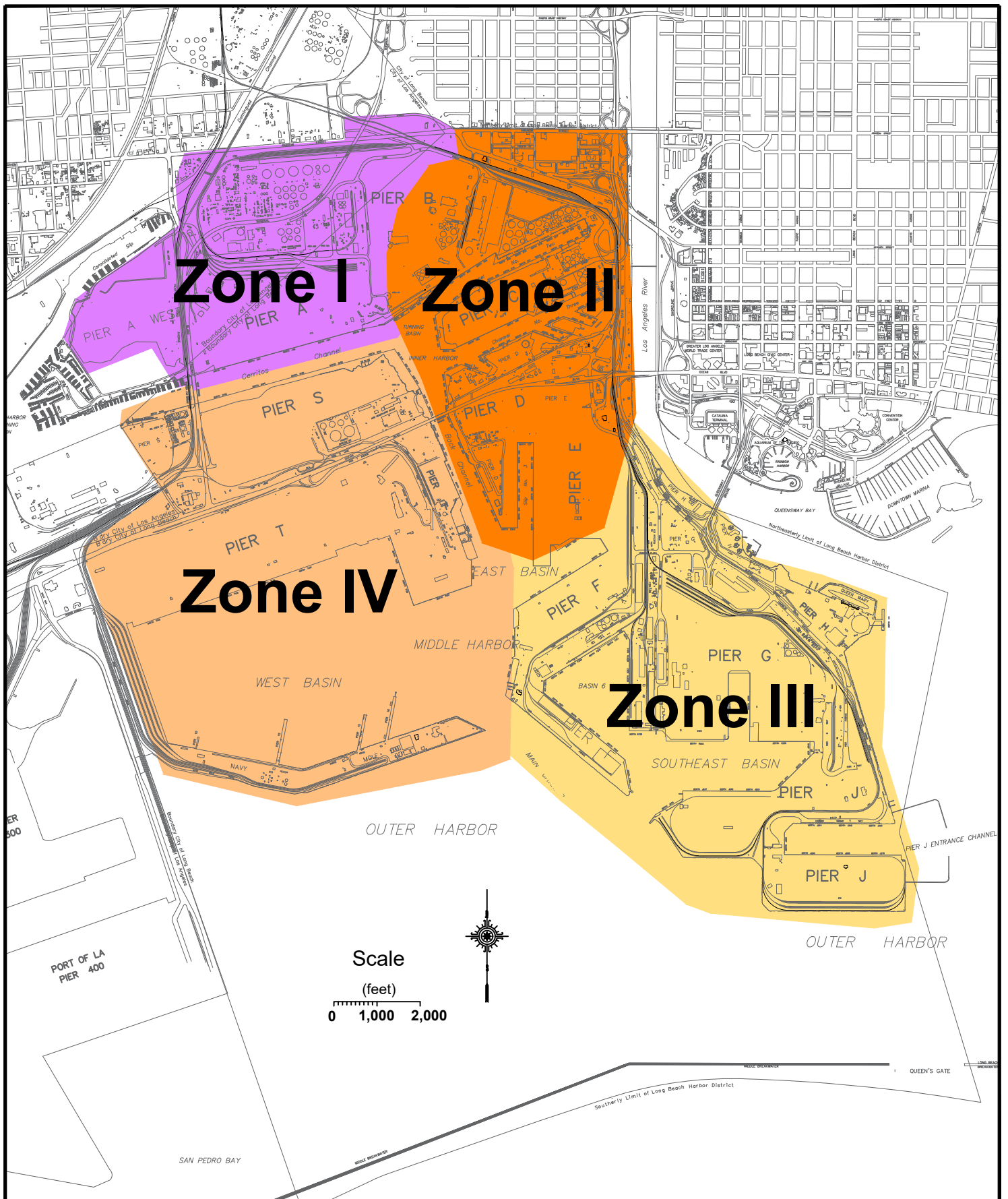
The depths of available soil borings and CPTs were typically on the order of 100 feet. The time-averaged shear wave velocity of 30 meters (100 feet) deep soil, $V_{s,30}$, below the existing hydraulic fill and harbor deposits were on the order of 300 m/s (approximately 1,000 ft/s). This depth in the 2020 PWGM study was considered sufficient in accordance with ASCE 7-16, which required characterization of soil profiles to a depth at which the underlying soils are classified as Site Class D or stiffer. However, ASCE 7-22 requires characterization of soil profiles to a depth at which the underlying soils are classified as Site Class C or stiffer. The $V_{s,30}$ value for Site Class C is at least about 450 m/s (approximately 1,500 ft/s). To develop the soil profiles that are sufficiently deep per the ASCE 7-22 requirement, deep shear wave velocity measurements that have been previously performed within the POLB were evaluated.

Deep shear wave velocity measurements were found at four locations within the POLB. These locations are shown on Figure 2-3. The depths of measured shear wave velocity profiles are approximately 160 feet at the Schuyler Heim Bridge (EMI, 2010), 180 feet at the Gerald Desmond Bridge (EMI-DYA, 2011), 290 feet at the Shoemaker Bridge (HDR, 2023), and approximately 1,050 feet at Pier F (ROSRINE, 2001). Because the geology east of the Palos Verdes Fault is similar across both the Port of Los Angeles and the Port of Long Beach, the shear wave velocity measurements obtained on the Terminal Island side of the Vincent Thomas Bridge at Port of Los Angeles were also considered in the characterization of the soil profiles. The information about the Port’s geology including regional physiography, stratigraphy, geologic structure, and

seismicity can be found in the 2020 PWGM study (EMI, 2020). The shear wave velocity measurement depths at Terminal Island side of the Vincent Thomas Bridge (east of the Palos Verdes Fault) range from approximately 200 to 300 feet (EMI, 1996).

The available deeper than 100 ft shear wave velocities profiles at the five locations discussed above are shown in Figure 2-4. As shown in the figure, the depth at which the underlying soils are classified as Site Class C ($V_{s,30} = 1,500$ ft/s) appears to be approximately 250 feet below existing grade. Below this elevation, subsurface conditions are dominated by the Gaspar Formation, which comprises dense to very dense sandy materials. The idealized best-estimate shear wave velocity profiles corresponding the four soil zones I, II, III, and IV are presented in Figure 2-5. The lower-estimate and upper-estimate shear wave velocities are also shown in the figure for comparison. Consistent with the 2020 PWGM study, the lower- and upper-bound profiles considered shear wave velocity profiles that were respectively 12 percent lower and higher than the best estimate shear wave velocities. This amount of variation corresponded to about 25 percent variability in the magnitude of small-strain shear modulus ($G_{\max}$).

Details of the soil profiles within soil zones I, II, III, and IV including soil stiffness and strength parameters are further elaborated in Section 4.2.



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Ground Motion Study Update,
Port of Long Beach, California**

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Date: April 2026

Soil Zones Representing Subsurface
Conditions at POLB

Figure 2-1

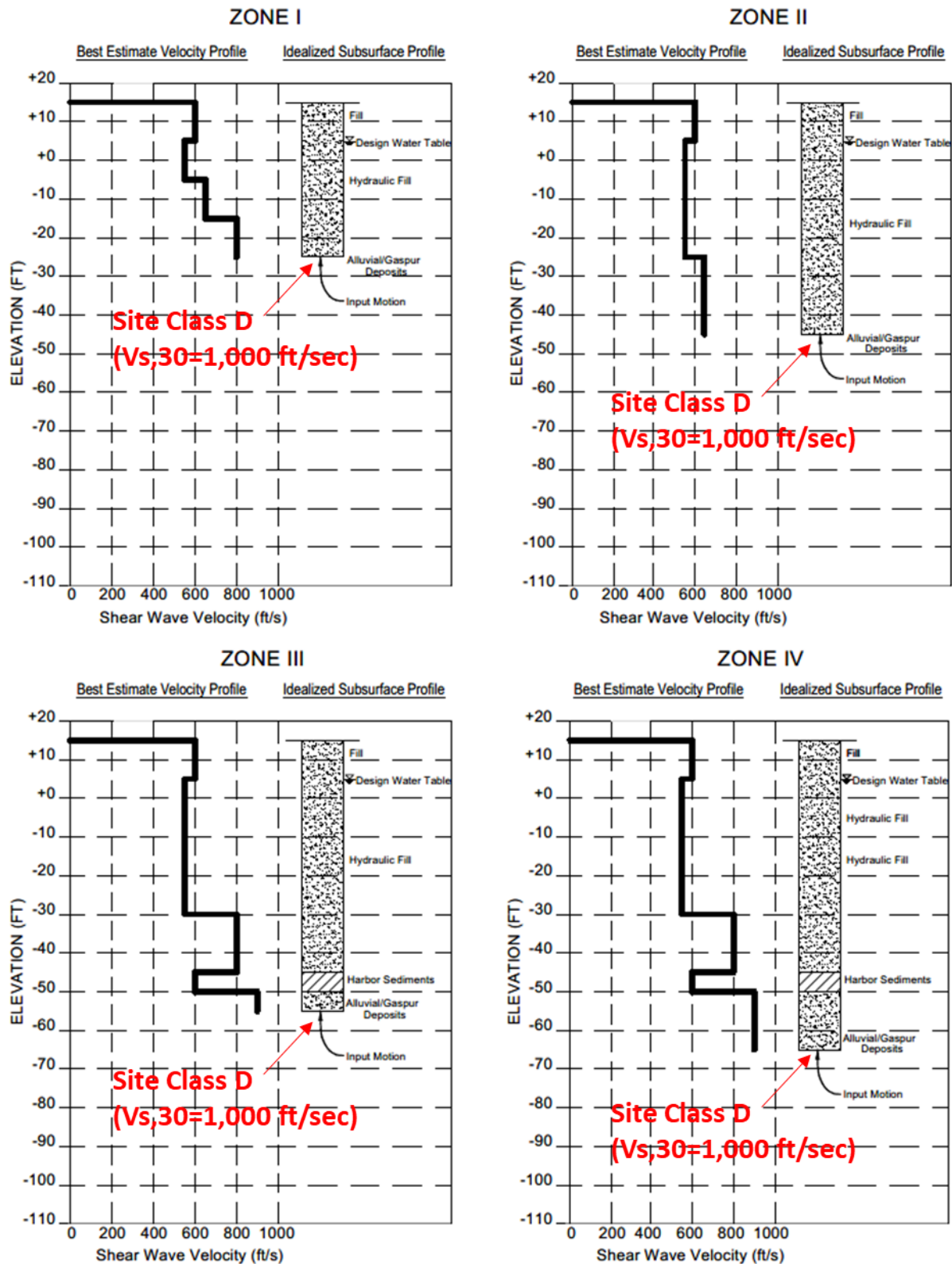


FIGURE 2-2 IDEALIZED SOIL PROFILES CONSIDERED IN THE 2006 AND 2020 PWGM STUDIES (EMI, 2006 AND 2020)



**FIGURE 2-3 LOCATIONS OF SHEAR WAVE VELOCITY MEASUREMENTS
EXCEEDING 100 FEET IN DEPTH**

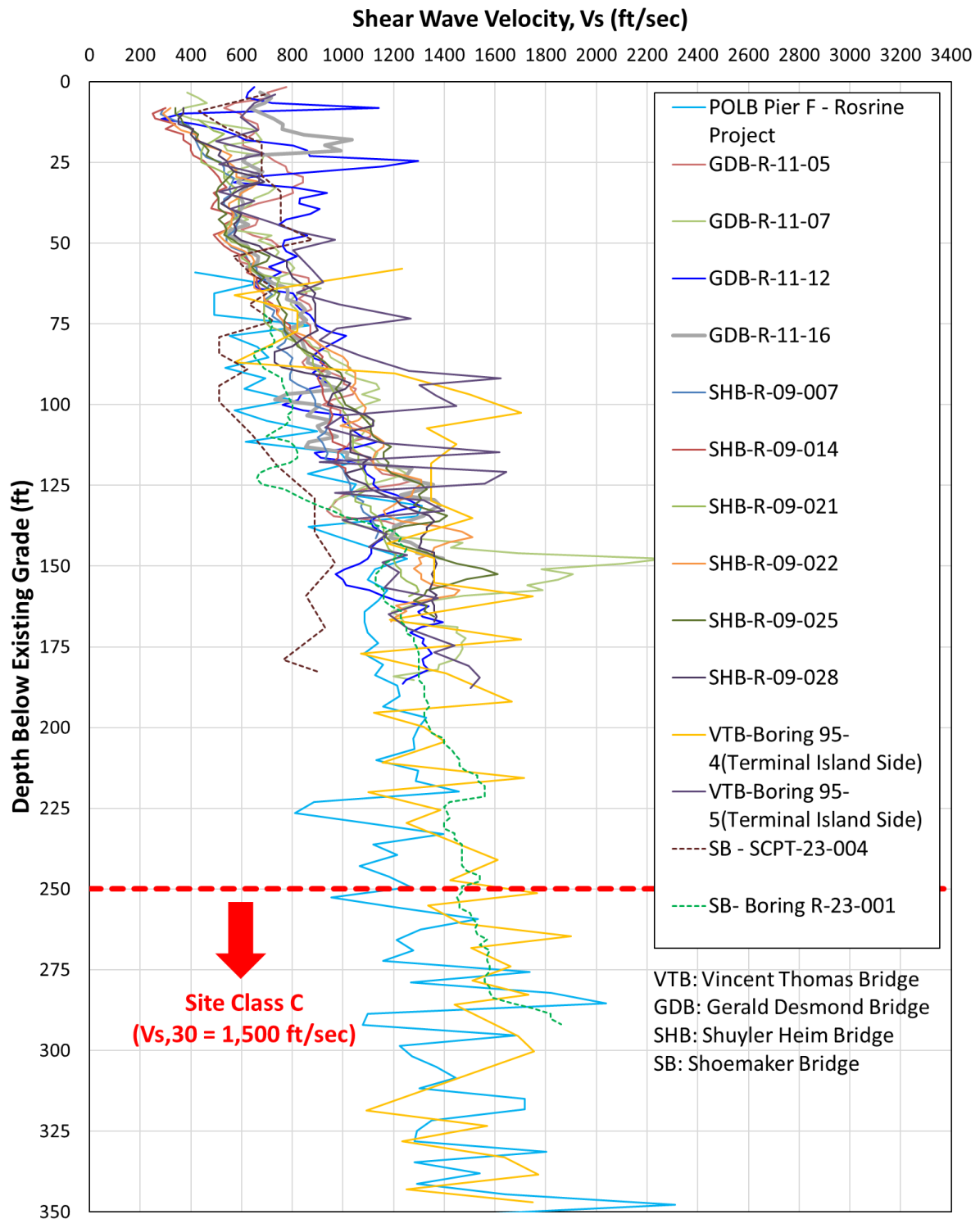


FIGURE 2-4 DEEP SHEAR WAVE VELOCITY PROFILES AND DEPTH OF SITE CLASS C

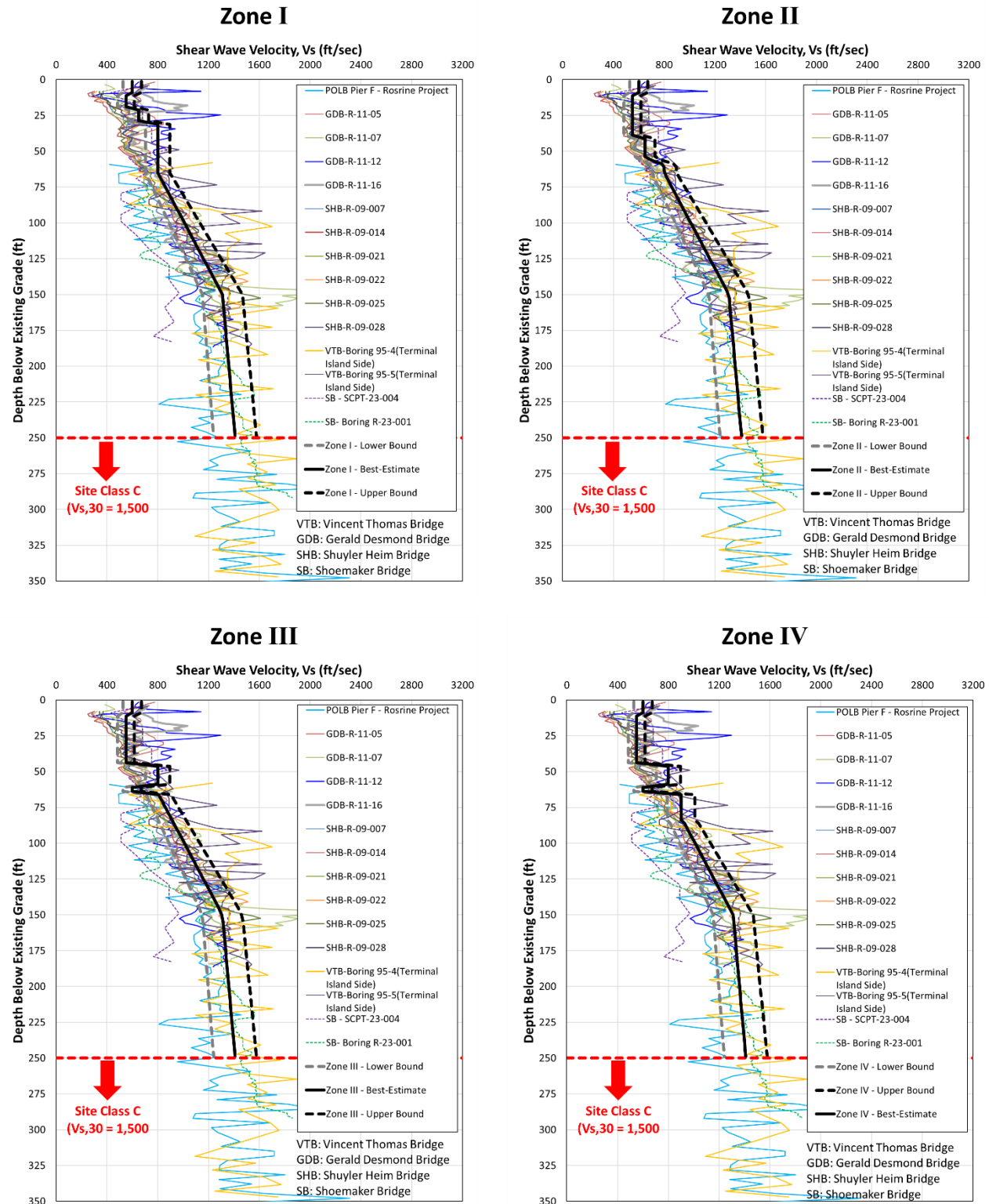


FIGURE 2-5 250-FT DEEP LOWER-, BEST-, AND UPPER-ESTIMATE SHEAR WAVE VELOCITY PROFILES CONSIDERED FOR SOIL ZONES I, II, III, AND IV IN THE PRESENT STUDY

3.0 PROBABILISTIC SEISMIC HAZARD ANALYSIS (PSHA)

3.1 Overview

The probabilistic seismic hazard analysis (PSHA) followed the standard approach initially developed by Cornell (1968). This approach has been expanded to fully treat both the randomness (aleatory variability) and the scientific uncertainty (epistemic uncertainty). The PSHA analyses were previously developed as part of a port-wide seismic hazard study for the Port of Long Beach (POLB) (EMI, 2020). These ground motions were developed following a standard PSHA methodology and the current state of knowledge and practice input models at the time of the study. These models include the seismic source characterization (SSC) and the ground motion characterization (GMC). The SSC was based on the current state of knowledge for crustal seismic source characterization for California developed in the Uniform California Earthquake Rupture Forecast Version 3 (UCERF3). The newly characterized Wilmington fault (Wolfe et al., 2019) located in the immediate area around the POLB was also included in SSC. Due to its relatively low recurrence interval of 3,490 to 4,490 years and also low slip rate of 0.14-0.18 mm/yr, the contribution of Wilmington fault in the PSHA study was found to be negligible for hazard levels of 2,475 years and less. In general, the inclusion of the Wilmington fault in the UCERF 3 database led to an increase of up to 4 percent in the ground motion spectral accelerations. Further discussions regarding the Wilmington Fault characteristics are provided in the 2020 PWGM study (EMI, 2020).

Four equally weighted Next Generation Attenuation models for Western US (NGA-West2) were used to predict ground motions for the PSHA study. The NGA-West 2 models are: Abrahamson et al. (2014) (referred to as ASK14), Boore et al. (2014) (referred to as BSSA14), Campbell and Bozorgnia (2014) (referred to as CB14), and Chiou and Youngs (2014) (referred to as CY14).

In accordance with the requirements of ASCE 7-22, Chapter 21, the probabilistic seismic hazard analysis (PSHA) was performed using a $V_{s,30}$ value of 450 m/s (1,500 ft/s). As discussed in Section 2.0, this $V_{s,30}$ value represents the average shear wave velocity below a depth of approximately 250 feet beneath the existing grade at the Port. In this study, this depth is referred to as the 'Reference Bedrock'.

Given the close proximity of multiple faults to POLB, near-fault directivity effects were incorporated into the PSHA. Three directivity models, Chiou and Spudich (2013), Bayless and Somerville (2013), and Bayless et al. (2020), were used to represent these effects. Consistent with the evaluations of Al Atik et al. (2022), the predicted directivity adjustments from the three models were combined using weighting factors of 0.50, 0.25, and 0.25, respectively.

Further details of the SSC, GMC, and methodologies used to consider ground motion directivity effects and develop vertical component of spectral responses are explained in Appendix A.

3.2 Reference Bedrock Risk-Targeted Response Spectrum per ASCE 7-22 Standards

The PSHA was performed for the reference bedrock to determine the uniform hazard spectrum of an earthquake event having return period of 2,475 years. Per Section 11.4.1 of ASCE 7-22, the POLB area is classified as near-fault site. Near-fault effects were incorporated into the PSHA, as briefly discussed in the previous section. Additional details regarding the PSHA and the methodologies used to account for near-fault effects are provided in Appendix A. Figure 3-1 presents the reference bedrock 5%-damped acceleration response spectrum corresponding to a 2,475-year return period, with near-fault effects included.

Per Chapter 21 of ASCE 7-22, the risk-targeted maximum considered earthquake (MCE_R) response acceleration at each vibration period is the lesser of probabilistic and deterministic MCE_R response accelerations. The probabilistic MCE_R response acceleration is taken as the spectral response accelerations in the direction of maximum horizontal response represented by a 5 percent damped acceleration response spectrum that is expected to achieve a 1 percent probability of collapse within a 50-year period. The probabilistic MCE_R is determined by applying the two modification factors: maximum direction and risk factors to the acceleration response spectra for the 2,475-year earthquake event.

Maximum Direction Factors: The spectral response accelerations predicted by the NGA-West 2 ground motion models do not represent the maximum response in the horizontal plane. Therefore, the 2,475-year return period response spectral accelerations computed from the hazard analysis are scaled by factors to increase the motions to the maximum response. Per ASCE 7-22, the scale factors of Shahi and Baker (2013) were used.

Risk Factors: To convert the maximum-direction uniform hazard response spectrum into a uniform risk spectrum corresponding to a 1 percent probability of collapse in 50 years, the methodology described in ASCE 7-22 Section 21.2.1 was adopted. Under this approach, the ordinates of the probabilistic acceleration response spectrum (ARS) at each vibration period are calculated as the product of the risk coefficient, C_R , and the maximum-direction spectral response acceleration from the 5 percent-damped response spectrum associated with a 2 percent probability of exceedance in 50 years (i.e., a 2,475-year mean return period). The risk coefficient, C_R , for each vibration period is determined through iterative integration of the site-specific hazard curve with a lognormal probability density function representing the collapse fragility. The iterative integration process was done using the USGS webtool (<https://earthquake.usgs.gov/nshmp/designmaps/rtgm>).

The deterministic MCE_R response acceleration at each period was calculated as a 84th-percentile 5 percent damped ARS in the direction of maximum horizontal response computed at that period. The envelope of the ARS calculated for the characteristic earthquakes on all known active faults within the region was used. The active faults Compton, Newport-Inglewood and Palos Verdes were considered in the deterministic analyses. The 2014 NGA West-2 GMPE spreadsheet (Seyhan, 2015) was adopted to run the analyses. The same ground motion models as used in the PSHA was used to estimate the spectral accelerations. The deterministic spectral acceleration at each period

was taken as not less than the deterministic lower limit response spectrum outlined in ASCE 7-22 Section 21.2.2.

Per section 21.2.3 of ASCE 7-22, the site-specific MCE_R at any period should not be taken less than 150% of the site-specific DE spectrum. The site-specific DE ARS is defined as two-thirds of the MCE_R spectral response acceleration, but not less than 80% of the acceleration response determined for the code-based site class in accordance with Section 21.3 of ASCE 7-22. Site Class C was considered to develop the lower bound (80% of site class C) ARS for the reference bedrock. The 150% of the envelope of these two spectra were considered as the site-specific MCE_R .

Figure 3-1 compares the deterministic and probabilistic ARS curves with the 80% of code-based MCE_R level ARS curve and recommends the reference bedrock ARS curve for the MCE_R event.

3.3 Selected Spectrally-Matched Ground Motion Time Histories For Reference Bedrock

Startup ground motions for spectrum compatible time histories were selected based on disaggregation results, as presented in Appendix A. Based on the disaggregation results, for return period of 2,475-yr, the magnitude (M_w) 6 to 7.5 events at distances up to 10 km have the most contribution, with decreasing contribution from magnitude 7.5 to 8 distant earthquakes on San Andreas fault for larger return periods.

Based on the above results, a suite of seven startup ground motion sets, as presented in Table 3-1, was adopted for the 2,475-year return period earthquake. Per Section 11.4.1 of ASCE 7-22, near-fault effects were incorporated into the selection of the startup motions by including three pulse-like records (Sets 2, 3, and 5). These ground motions are consistent with those used in the 2020 PWGM study (EMI, 2020).

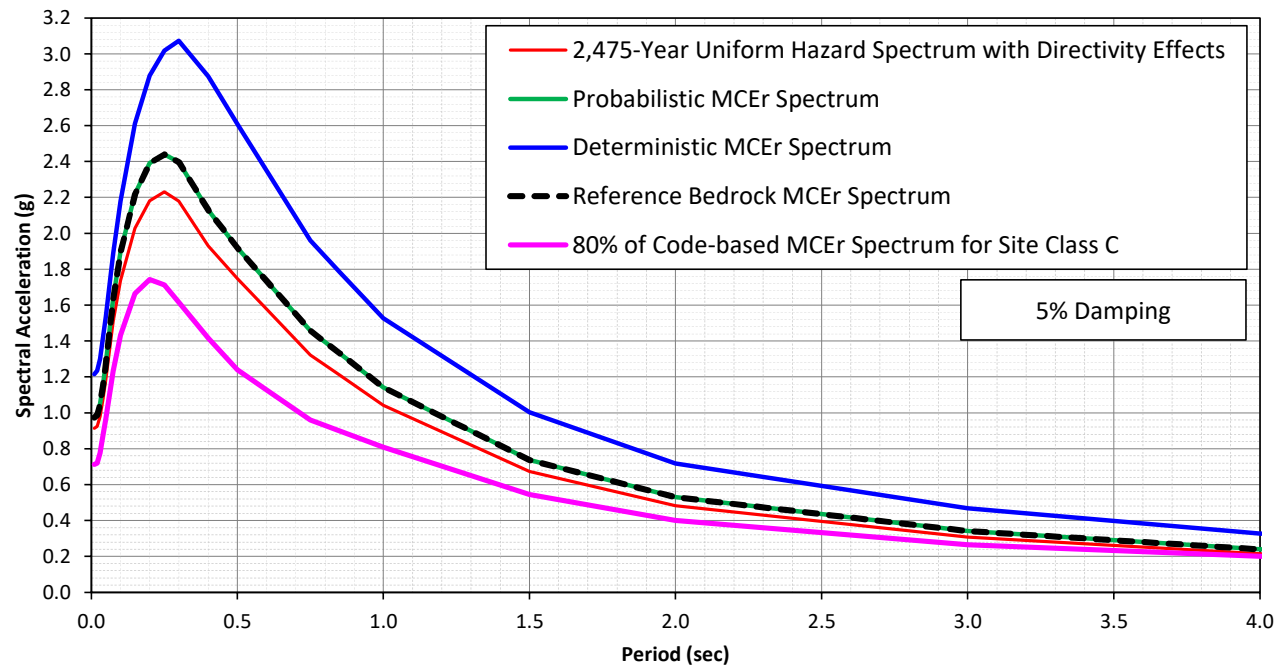
The selected startup ground motions were modified to match the reference bedrock MCE_R presented in Figure 3-1. The spectrum-matching process was performed using the computer program RSPMATCH (Abrahamson, 1992), which applies a time-domain approach to adjust the spectral response of the input motions to match a target acceleration response spectrum. The objective of this approach is to preserve the general nonstationary characteristics of the ground motion, specifically acceleration, velocity, and displacement time histories, while modifying the spectral content to achieve compatibility with the target response spectrum.

The initial three-component time histories, modified time histories, and comparison of the matched spectra with the reference bedrock response spectrum are shown in Appendix B.

Table 3-1 Selected Startup Motions for a 2475-yr Return Period Earthquake

Set	PEER RSN *	Earthquake	Mw	Pulse Motion	Station	Distance, R _{rup} (km)
1	1787	1999 Hector Mine	7.1	No	Hector	11.7
2	767	1989 Loma Prieta	6.9	Yes	Gilroy Array 0#3	12.8
3	2114	2002 Denali, Alaska	7.9	Yes	TAPS Pump Station #10	2.7
4	1612	1999 Duzce, Turkey	7.1	No	Lamont 1059	4.2
5	6906	2010 Darfield, New Zealand	7.0	Yes	GDLC	1.2
6	6	1940 Imperial Valley	6.9	No	El Centro	6.1
7	1108	1995 Kobe, Japan	6.9	No	Kobe University	0.9

* PEER ground motion database (<https://ngawest2.berkeley.edu/>).



Period	2,475-Year Uniform Hazard Spectrum with Directivity *	Probabilistic MCEr Spectrum	Deterministic MCEr Spectrum	Reference Bedrock MCEr Spectrum	80% of Code- based MCEr Spectrum for Site Class C
T (sec)	Sa (g)	Sa (g)	Sa (g)	Sa (g)	Sa (g)
0.010	0.913	0.974	1.215	0.974	0.712
0.020	0.925	0.989	1.234	0.989	0.720
0.030	0.979	1.050	1.300	1.050	0.776
0.040	1.073	1.154	1.418	1.154	0.872
0.050	1.187	1.280	1.537	1.280	0.968
0.075	1.509	1.637	1.887	1.637	1.232
0.100	1.738	1.898	2.179	1.898	1.432
0.150	2.028	2.219	2.610	2.219	1.664
0.200	2.181	2.391	2.878	2.391	1.744
0.250	2.231	2.440	3.017	2.440	1.712
0.300	2.179	2.396	3.074	2.396	1.616
0.400	1.930	2.129	2.875	2.129	1.416
0.500	1.749	1.919	2.610	1.919	1.240
0.600	1.579	1.736	2.351	1.736	1.128
0.750	1.323	1.457	1.959	1.457	0.960
0.850	1.212	1.332	1.786	1.332	0.899
1.000	1.041	1.142	1.526	1.142	0.808
1.500	0.673	0.738	1.003	0.738	0.544
2.000	0.483	0.530	0.717	0.530	0.400
3.000	0.308	0.341	0.469	0.341	0.264
4.000	0.215	0.240	0.327	0.240	0.200
5.000	0.157	0.176	0.240	0.176	0.160
7.500	0.086	0.097	0.119	0.097	0.096
10.000	0.055	0.063	0.072	0.063	0.062

* The uniform hazard spectrum is the envelope of the spectra for Sites 1, 3, 5, and 8 from the PSHA study (see Appendix A). The spectrum incorporates directivity effects.



Addendum No. 1 to the 2020 Port-Wide Ground Motion Study Update, Port of Long Beach, California

EMI Project No: 20-150-2

Date: April 2026

**Reference Bedrock (Site Class C) MCE_R
Response Spectrum Developed Based on
ASCE 7-22**

Figure 3-1

4.0 SITE RESPONSE ANALYSIS

4.1 Methodology

One-dimensional (1-D) site response analyses were conducted to develop ground motions at the ground surface. In the site response analyses, the reference bedrock startup motions discussed in the previous section were applied to the base of representative soil profiles and the motions were allowed to propagate from the reference bedrock elevation (site class C) up to the ground surface. To simulate 1D wave propagation and capture nonlinear stress-strain response of the soil materials, a nonlinear time-domain analysis approach was adopted using the computer program RS seismic (Rocscience, 2026). Unlike equivalent linear analysis, which is performed in frequency domain, the nonlinear analysis solves the equations of motion in time domain, using the Newmark- β method.

4.2 Soil Profiles and Properties

The soil profiles shown in Figure 2-2 and Figure 2-4 for Zones I, II, III, and IV were analyzed using the computer program RS seismic (Rocscience, 2026). Consistent with the approach adopted in the 2020 PWGM study, three sets of soil properties were considered for each zone to account for spatial variability and uncertainties in the estimation of material stiffness and strength parameters: lower-bound, upper-bound, and liquefied conditions.

The lower- and upper-bound profiles incorporated shear wave velocity (V_s) values that were 12 percent lower and higher, respectively, than the best-estimate V_s profile shown in Figure 2-4. This variation corresponds to approximately 25 percent variability in the small-strain shear modulus (G_{max}). The analyses assumed lower- and upper-bound friction angles of 32° and 35° , respectively, and lower- and upper-bound cohesion values of 50 psf and 100 psf, respectively, for the hydraulic fill. The lower- and upper-bound undrained shear strengths of the harbor sediments encountered in Zones III and IV were assumed to be 1,000 psf and 2,500 psf, respectively. The underlying competent soils (Gaspur Deposits) were assigned lower- and upper-bound friction angles of 35° and 38° , respectively, within the upper 20 ft of the layer, and 38° and 40° , respectively, below that depth. A cohesion value of 100 psf was assumed throughout the full thickness of the Gaspur Deposits.

For liquefied conditions, the residual shear strength was estimated as 0.15 times the in-situ vertical effective stress (σ'_v), following the methodology of Idriss and Boulanger (2008). The shear wave velocity profile below the groundwater table (i.e., within liquefiable soils) was correlated using the relationship proposed by Dickenson (1994).

The input lower- and upper-bound and liquefied conditions soil parameters for all four zones are presented in Appendix C.

4.3 Shear Modulus Reduction and Damping Ratio Models

Consistent with the 2020 PWGM study (EMI, 2020), the dynamic shear modulus ($G/G_{\max}$) and damping ($D/D_{\max}$) curves for hydraulic fill were estimated using the empirical relationships by EPRI (1993). For the harbor sediments, the shear modulus and damping curves of Vucetic and Dobry (1991) were adopted, assuming lower- and upper-bound plasticity index (PI) of 20 and 50. For liquefied soils, the Vucetic and Dobry (1991) curves corresponding to $PI = 0$ were used.

To improve model accuracy at large strain levels, the reference modulus reduction and damping curves were used to fit a general quadratic/hyperbolic (GQ/H) backbone curve, as described by Groholski et al. (2016) and implemented in RS seismic (Rocscience, 2026). In addition, the reference damping curves were used to fit unloading-reloading relationship using modulus reduction and damping curve fitting (MRDF)-Darendeli Model (Darendeli, 2001) as available in the RS seismic soil model libraries.

This fitting procedure was applied to each layer in the soil profile, resulting in a calibrated soil model that more accurately represents both small-strain stiffness and large-strain strength behavior.

4.4 Input Ground Motions

The seven sets of spectrally-matched reference bedrock (Site Class C) startup ground motions presented in Appendix B were applied to the base of the soil profiles as outcropping motions. Since these ground motions were outcrop motions, the elastic half-space option was used to simulate downward and upward propagating motions at the base of the soil profiles. The shear wave velocity of the half-space was assumed to be 1,500 ft/s.

4.5 Site Response Analysis Results

Given that (i) the considered MCE_R event comprised of fourteen (14) ground motion time histories, (ii) three different soil properties, i.e., lower- and upper-bound, and liquefied conditions, and (iii) four different soil zones I, II, III, and IV, a total of 168 ($=14 \times 3 \times 4$) site response analyses were performed to develop unimproved ground response spectra at the ground surface. The spectral responses at the ground surface for each soil zone and soil profiles are presented in Appendix D.

The acceleration response spectra at the ground surface obtained from fourteen ($=2 \times 7$) ground motions were averaged (geometric mean) for each soil condition and then enveloped for all soil profiles to develop the design response spectrum at the ground surface for each soil zone. As expected, the upper-bound soil profile controlled the spectral responses at short periods and the lower-bound soil profile controlled the spectral response at long periods for each soil zone and ground motion. Spectral responses were much smaller in the liquefied soil profile which just showed slightly larger spectral accelerations in periods greater than 1.0 second. The response spectra are presented in Appendix D. All ARS curves are developed for 5 percent damping ratio.

Considerable reduction in spectral accelerations was noted at periods less than 1.0 second compared to the reference bedrock spectral accelerations for the MCE_R event. This is because the MCE_R level ground motions impart large seismic forces into the unimproved ground (hydraulic fill) mobilizing excessive soil nonlinearity and energy damping which can be potentially overestimated in the site response analyses. In order to account for the uncertainties associated with estimation of soil nonlinearity under such extreme earthquake events, consistent with the 2020 PWGM study, the site response analysis results were enveloped with the spectral accelerations for the firm (improved) ground. Consistent with the previous 2006 and 2020 PWGM studies the firm (improved) ground is defined as ground having $V_{s,30}$ of 1,000 ft/sec (approximately 300 m/sec).

The recommended DE response spectra for both firm (improved) and unimproved grounds are presented in the next section.

5.0 DESIGN RECOMMENDATIONS BASED ON ASCE 7-22

5.1 Firm (Improved) Ground DE Response Spectrum

The PSHA that was completed for the firm (improved) Ground ($V_{s,30}=1,000$ ft/sec) for a 2,475-year return period earthquake as part of the 2020 PWGM study was adopted here to develop firm ground DE response spectrum in accordance with provisions of ASCE 7-22. The same procedure outlined in Section 3.2 was followed to convert the uniform hazard spectrum obtained from the PSHA for a site with $V_{s,30}=1,000$ ft/sec to the risk-targeted maximum considered earthquake (MCE_R). Deterministic seismic hazard analyses as described in Section 3.2 were repeated considering $V_{s,30}$ of 1,000 ft/sec. Per Section 21.3 of ASCE 7-22, the DE ARS is defined as two-thirds of the MCE_R spectral response acceleration, but no less than 80% of the acceleration response determined for site class D in accordance with ASCE 7-22.

Figure 5-1 compares the deterministic and probabilistic response spectra with the 80% of code-based MCE_R level ARS curve and recommends the DE response spectrum.

5.2 Unimproved Ground DE Response Spectrum

The provisions of ASCE 7-22 – Chapter 21 were adopted to develop the DE response spectrum from the MCE_R level spectral accelerations that were estimated from the site response analyses. Per Section 21.3 (ASCE 7-22), the DE ARS is defined as two-thirds of the MCE_R spectral response acceleration, but no less than 80% of the acceleration response determined for the same site class in accordance with ASCE 7-22. To account for uncertainties associated with characterization of hydraulic fill within the port, the lower limit for DE acceleration response was calculated for both Site Classes D and E.

As mentioned earlier to account for the uncertainties associated with estimation of soil nonlinearity under such an extreme earthquake event, the unimproved ground DE ARS curve was enveloped with the firm (improved) ground DE response spectrum.

Figure 5-2 presents a comparison of 80% of the Site Class D and E spectra with the response spectra obtained from the site response analyses, as well as the firm (improved) ground response spectrum. The enveloped MCE_R response spectrum for unimproved ground is presented in the figure.

In the 2020 PWGM study (EMI, 2020), two separate Design Earthquake (DE) response spectra were developed for unimproved ground conditions for Areas A and B within the Port. However, as shown in Figure 5-2, following the requirements of ASCE 7-22 the response spectra calculated for all four soil zones fall below 80% of the Site Class D and E spectra. Accordingly, this study recommends adoption of a single DE response spectrum, developed in accordance with ASCE 7-22, for use across the entire POLB.

Figure 5-3 further compares the recommended acceleration response spectra for firm (improved) and unimproved ground. Figure 5-4 shows the corresponding relative displacement response spectra.

5.3 Vertical Response Spectra

The response spectra for vertical component ground motions were developed by applying period-dependent vertical-to-horizontal (V/H) ratios to the horizontal response spectra discussed in the previous section. Details of V/H ratio calculations are presented in Section 5 of Appendix A.

Site response effects are expected to be nominal for vertical component of ground motions. Therefore, the reference bedrock vertical ARS can be also used for ground surface. Recommended vertical response spectra DE for 5% damping are shown in Figure 5-5.

Per ASCE 7-22 Section 11.9, the ordinates of the DE vertical ARS were checked to be greater than or equal to 80% of S_{av} values determined following Sections 11.9.2 and 11.9.3 of ASCE 7-22.

5.4 Horizontal and Vertical Response Spectra for Other Damping Ratios

The spectral responses for other damping ratios can be correlated from the 5% damping spectral responses using the methodology outlined in the Pacific Earthquake Engineering Research Center (PEER) report by Rezaeian et al. (2012). The approach outlines a procedure to determine a Damping Scaling Factor (DSF) that is expressed as:

$$DSF = \frac{\text{Spectral acceleration for a } \xi\% \text{ damping ratio } (S_{a\xi})}{\text{Spectral acceleration for a 5\% damping ratio } (S_{a\xi=5\%})}$$

The same DSFs for the horizontal and vertical components previously recommended for the Design Earthquake (DE) in the 2020 PWGM study (EMI, 2020) are adopted herein. The DSFs for damping ratios of 1%, 2%, 10%, 15%, 20%, and 25% are presented in Table 5-1 and Table 5-2 for the horizontal and vertical DE spectra, respectively.

By definition, spectral responses at a given damping ratio may be obtained by multiplying the 5%-damped spectral acceleration by the corresponding DSF provided in the tables.

TABLE 5-1 Damping Scaling Factors to Determine Horizontal Component of Spectral Acceleration For Damping Ratios (ξ) 1, 2, 10, 15, 20, and 25% for DE Event

Period (sec)	Damping Scaling Factor ($Sa_{\xi}/Sa_{\xi=5\%}$)					
	$\xi = 1\%$	$\xi = 2\%$	$\xi = 10\%$	$\xi = 15\%$	$\xi = 20\%$	$\xi = 25\%$
0.01	1.000	1.000	1.000	1.000	1.000	1.000
0.05	1.225	1.115	0.932	0.898	0.877	0.862
0.075	1.356	1.186	0.889	0.831	0.793	0.766
0.1	1.421	1.226	0.858	0.782	0.732	0.695
0.2	1.539	1.299	0.800	0.694	0.624	0.573
0.3	1.515	1.295	0.793	0.681	0.608	0.554
0.4	1.505	1.295	0.788	0.674	0.598	0.542
0.5	1.486	1.287	0.789	0.674	0.598	0.542
0.75	1.467	1.282	0.785	0.666	0.588	0.530
1	1.415	1.257	0.794	0.679	0.602	0.545
1.5	1.399	1.249	0.802	0.690	0.614	0.558
2	1.357	1.224	0.812	0.705	0.632	0.578
3	1.314	1.200	0.829	0.730	0.662	0.610
4	1.284	1.184	0.838	0.742	0.675	0.624
5	1.249	1.167	0.841	0.746	0.680	0.629
7.5	1.239	1.160	0.851	0.761	0.697	0.648
10	1.160	1.114	0.877	0.800	0.743	0.699

TABLE 5-2 Damping Scaling Factors to Determine Vertical Component of Spectral Accelerations For Damping Ratios (ξ) 1, 2, 10, 15, 20, and 25% for DE Event

Period (sec)	Damping Scaling Factor ($Sa_{\xi}/Sa_{\xi=5\%}$)					
	$\xi = 1\%$	$\xi = 2\%$	$\xi = 10\%$	$\xi = 15\%$	$\xi = 20\%$	$\xi = 25\%$
0.01	1.000	1.000	1.000	1.000	1.000	1.000
0.02	1.044	1.025	0.982	0.972	0.965	0.960
0.03	1.210	1.111	0.930	0.893	0.869	0.851
0.05	1.494	1.260	0.841	0.758	0.703	0.664
0.08	1.621	1.335	0.788	0.678	0.607	0.556
0.1	1.664	1.358	0.772	0.656	0.582	0.528
0.15	1.677	1.366	0.766	0.648	0.572	0.517
0.2	1.618	1.342	0.775	0.658	0.582	0.528
0.3	1.574	1.321	0.781	0.666	0.591	0.537
0.5	1.524	1.302	0.786	0.670	0.595	0.539
0.75	1.486	1.290	0.784	0.666	0.588	0.530
1	1.478	1.287	0.786	0.668	0.590	0.533
2	1.414	1.258	0.792	0.676	0.598	0.541
4	1.303	1.203	0.814	0.706	0.631	0.575
5	1.271	1.186	0.824	0.718	0.645	0.590
7.5	1.179	1.129	0.866	0.781	0.721	0.673
10	1.146	1.103	0.897	0.830	0.780	0.742

5.5 Seismic Parameters for Geotechnical Evaluations

Table 5-3 presents the recommended PGA and earthquake magnitudes (M_w) that can be used for liquefaction, slope stability and lateral spread analyses. The PGA for each earthquake event was taken as the larger of the PGA values estimated for firm (improved) ground and unimproved ground. MCE_G level parameters are additionally provided in the table below since per ASCE 7-22 (chapters 12 and 15) for any building structures, all geotechnical evaluations should be performed considering the geometric mean maximum considered earthquake (MCE_G). The DE level PGA was taken as two-thirds of the MCE_G level PGA.

The DE level PGA values shown in Figure 5-3 at the period of 0.01 second were not used here because the values in the graphs were derived from maximum-direction acceleration spectrum with 1% probability of building collapse in 50 years (MCE_R) which is applicable for structural calculations only not for geotechnical evaluations such as liquefaction or lateral spread analyses. It should be noted that the DE level PGA for geotechnical evaluations is denoted as DE_G in this study to avoid confusion with two-thirds of MCE_R that is used in structural evaluations.

Table 5-3 Summary of Design Earthquake Parameters for Geotechnical Evaluations

Earthquake Event	Peak Ground Acceleration (PGA)	Earthquake Magnitude (M_w)
DE_G ¹	0.60g	7.3
MCE_G ²	0.90g	7.3

1. DE_G is defined as two-thirds of MCE_G .

2. Per ASCE 7-22, MCE_G is defined as maximum considered earthquake geometric mean event which has 2% probability of exceedance in 50 years (a return period of 2,475 years).

5.6 Newmark Displacements for Kinematic Analysis

Simplified Newmark sliding block-type analyses were conducted to estimate lateral ground displacements under DE_G level earthquake. For buildings and human-occupied structures, ASCE 7-22 (Chapters 12 and 15) requires determination of lateral ground movements induced by a geometric mean maximum considered earthquake (MCE_G) event. Therefore, in addition to the earthquake events above, Newmark analysis was completed for MCE_G level events. Slope displacements were estimated using the suite of firm (improved) ground outcropping motions. Newmark sliding block displacements for varying yield accelerations were estimated by double-integrating the difference of the applied acceleration and the yield accelerations with respect to time. The resulting average lateral displacement versus yield acceleration curves for twenty-eight (28) time history components and directions (7 records $\times$ 2 components $\times$ 2 directions) is presented in Figure 5-6. For estimation of Newmark displacements under the DE event, the ground motions

were taken as two-thirds of the MCE_G -level motions, and the corresponding Newmark displacement curve is denoted as DE_G in Figure 5-6.

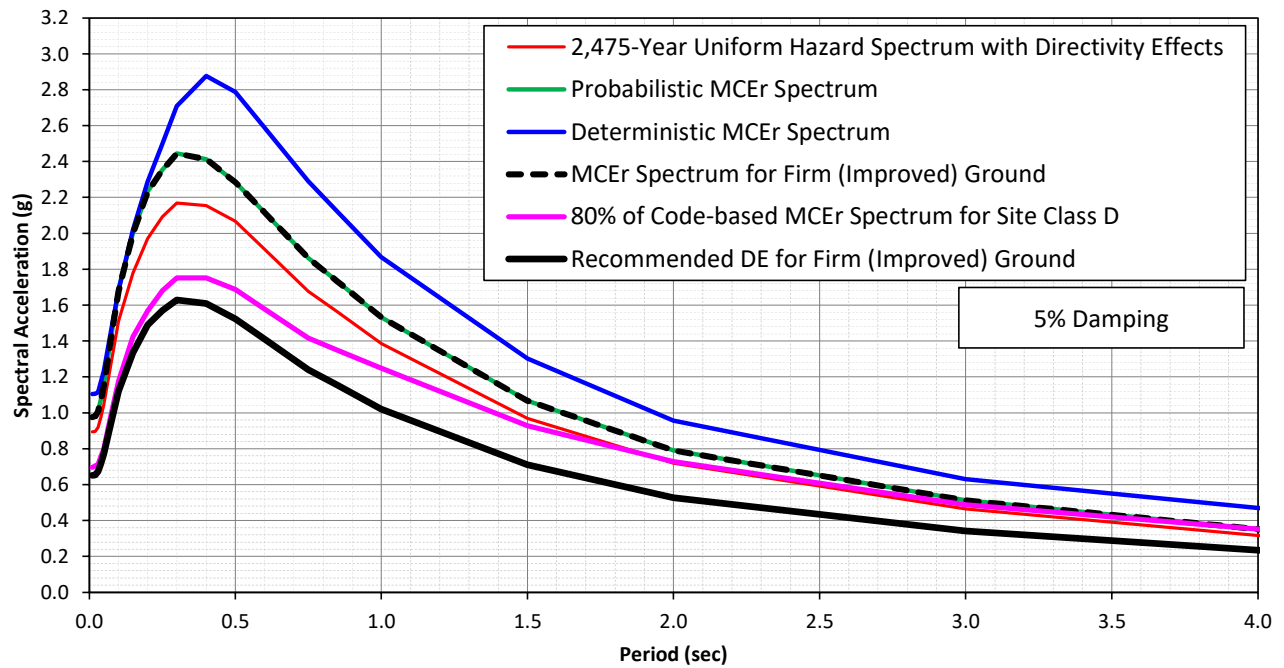
As the DE_G and MCE_G spectra are the same in ASCE 7-16 and ASCE 7-22, the Newmark displacement results are consistent with those presented in the 2020 PWGM Study (EMI, 2020).

These analyses are based on the firm-ground outcropping motions; therefore, the recommended curves are considered conservative and may be used as a screening tool to determine whether a particular project requires further evaluations such as site-specific soil-structure interaction analysis. The benefits of such analyses to the project should be clearly demonstrated. Approval for such analyses should be obtained from the Port before performing the analyses.

5.7 Spectrum-Matched Ground Motion Time Histories

Spectrum-matched ground motion time histories at ground surface of improved and unimproved grounds for DE are presented in Appendix E. In addition, digital formats of the time histories are provided in a Zip file attached to this memorandum.

The DE level time histories can be used for 2D analyses, only. For 3D analyses, spectrum-matching of the startup motions to the DE spectrum is expected to be too conservative. The DE event ARS represents the maximum spectrum of all orientations (RotD100); therefore, the design earthquake intensity can be potentially overestimated in a 3D analysis if both horizontal components of a motion are matched to the maximum-direction spectrum. The method outlined in ASCE 7-22 – Section 16.2 should be followed to develop the appropriate components of the DE ground motions.



Period	2,475-Year Uniform Hazard Spectrum with Directivity *	Probabilistic MCER Spectrum	Deterministic MCER Spectrum	MCER Spectrum for Firm (Improved) Ground	80% of Code- based MCER Spectrum for Site Class D	Recommended DE for Firm (Improved) Ground
T (sec)	Sa (g)	Sa (g)	Sa (g)	Sa (g)	Sa (g)	Sa (g)
0.010	0.894	0.977	1.105	0.977	0.696	0.651
0.020	0.895	0.981	1.106	0.981	0.704	0.654
0.030	0.919	1.009	1.114	1.009	0.712	0.673
0.040	0.977	1.076	1.174	1.076	0.756	0.717
0.050	1.047	1.157	1.234	1.157	0.800	0.771
0.075	1.280	1.423	1.460	1.423	0.992	0.948
0.100	1.510	1.690	1.682	1.682	1.176	1.121
0.150	1.778	2.001	2.019	2.001	1.424	1.334
0.200	1.971	2.233	2.288	2.233	1.568	1.489
0.250	2.092	2.354	2.499	2.354	1.680	1.569
0.300	2.170	2.445	2.708	2.445	1.752	1.630
0.400	2.154	2.414	2.877	2.414	1.752	1.609
0.500	2.066	2.284	2.786	2.284	1.688	1.523
0.600	1.912	2.116	2.589	2.116	1.579	1.411
0.750	1.677	1.861	2.290	1.861	1.416	1.241
0.850	1.563	1.731	2.121	1.731	1.349	1.154
1.000	1.386	1.532	1.868	1.532	1.248	1.021
1.500	0.968	1.067	1.302	1.067	0.928	0.711
2.000	0.719	0.790	0.956	0.790	0.728	0.527
3.000	0.465	0.513	0.630	0.513	0.488	0.342
4.000	0.317	0.353	0.470	0.353	0.352	0.235
5.000	0.229	0.255	0.360	0.264	0.264	0.176
7.500	0.121	0.135	0.190	0.144	0.144	0.096
10.000	0.075	0.086	0.110	0.088	0.088	0.059

* The uniform hazard spectrum is the envelope of the spectra for Sites 1, 3, 5, and 8 from the PSHA study (see Appendix A). The spectrum incorporates directivity effects.



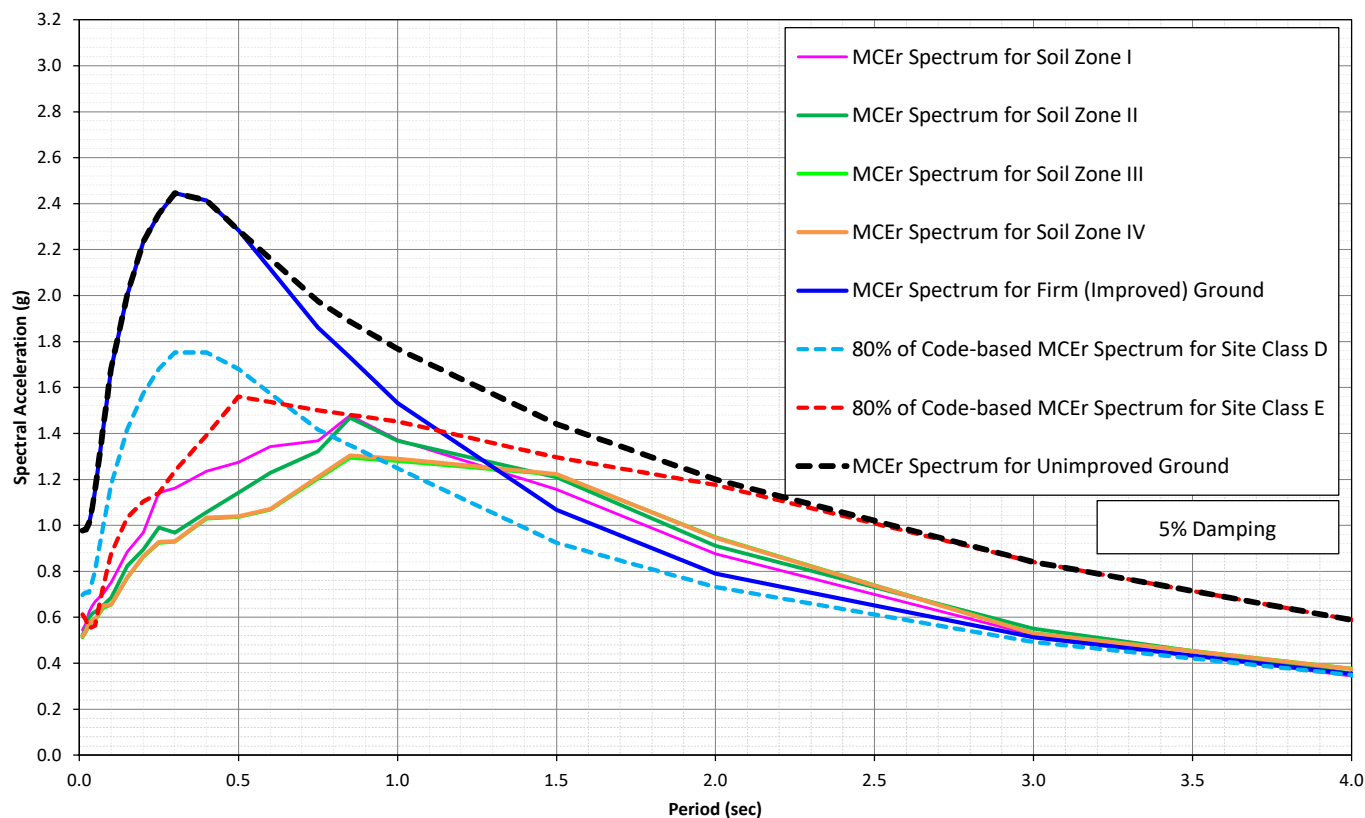
Addendum No. 1 to the 2020 Port-Wide Ground Motion Study Update, Port of Long Beach, California

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**Recommended DE Response Spectrum
Developed Based on ASCE 7-22 for Firm
(Improved) Ground**

Figure 5-1



Period (sec)	MCEr Spectrum for Soil Zone I	MCEr Spectrum for Soil Zone II	MCEr Spectrum for Soil Zone III	MCEr Spectrum for Soil Zone IV	MCEr Spectrum for Firm (Improved) Ground	80% of Code-based MCEr Spectrum for Site Class D	80% of Code-based MCEr Spectrum for Site Class E	MCEr Spectrum for Unimproved Ground
T (sec)	Sa (g)	Sa (g)	Sa (g)	Sa (g)	Sa (g)	Sa (g)	Sa (g)	Sa (g)
0.010	0.545	0.521	0.513	0.517	0.977	0.696	0.612	0.977
0.020	0.573	0.553	0.539	0.540	0.981	0.708	0.588	0.981
0.030	0.624	0.600	0.566	0.577	1.009	0.708	0.552	1.009
0.040	0.651	0.615	0.587	0.586	1.076	0.756	0.558	1.076
0.050	0.669	0.624	0.590	0.591	1.157	0.804	0.564	1.157
0.075	0.704	0.652	0.642	0.651	1.423	0.996	0.732	1.423
0.100	0.753	0.685	0.655	0.657	1.682	1.176	0.876	1.682
0.150	0.885	0.824	0.772	0.774	2.001	1.416	1.032	2.001
0.200	0.968	0.895	0.862	0.866	2.233	1.572	1.104	2.233
0.250	1.142	0.991	0.924	0.927	2.354	1.680	1.140	2.354
0.300	1.161	0.968	0.929	0.930	2.445	1.752	1.236	2.445
0.400	1.235	1.058	1.029	1.033	2.414	1.752	1.392	2.414
0.500	1.275	1.142	1.036	1.040	2.284	1.680	1.560	2.284
0.600	1.343	1.229	1.068	1.072	2.116	1.574	1.536	2.160
0.750	1.368	1.322	1.203	1.211	1.861	1.416	1.500	1.975
0.850	1.478	1.468	1.294	1.303	1.731	1.349	1.481	1.886
1.000	1.372	1.368	1.280	1.290	1.532	1.248	1.452	1.767
1.500	1.156	1.209	1.220	1.224	1.067	0.924	1.296	1.440
2.000	0.877	0.912	0.949	0.946	0.790	0.732	1.176	1.200
3.000	0.523	0.551	0.532	0.530	0.513	0.492	0.840	0.840
4.000	0.345	0.356	0.377	0.375	0.353	0.348	0.588	0.588
5.000	0.258	0.261	0.299	0.296	0.264	0.264	0.432	0.432
7.500	0.142	0.149	0.159	0.157	0.144	0.144	0.228	0.228
10.000	0.084	0.088	0.090	0.089	0.088	0.089	0.132	0.132



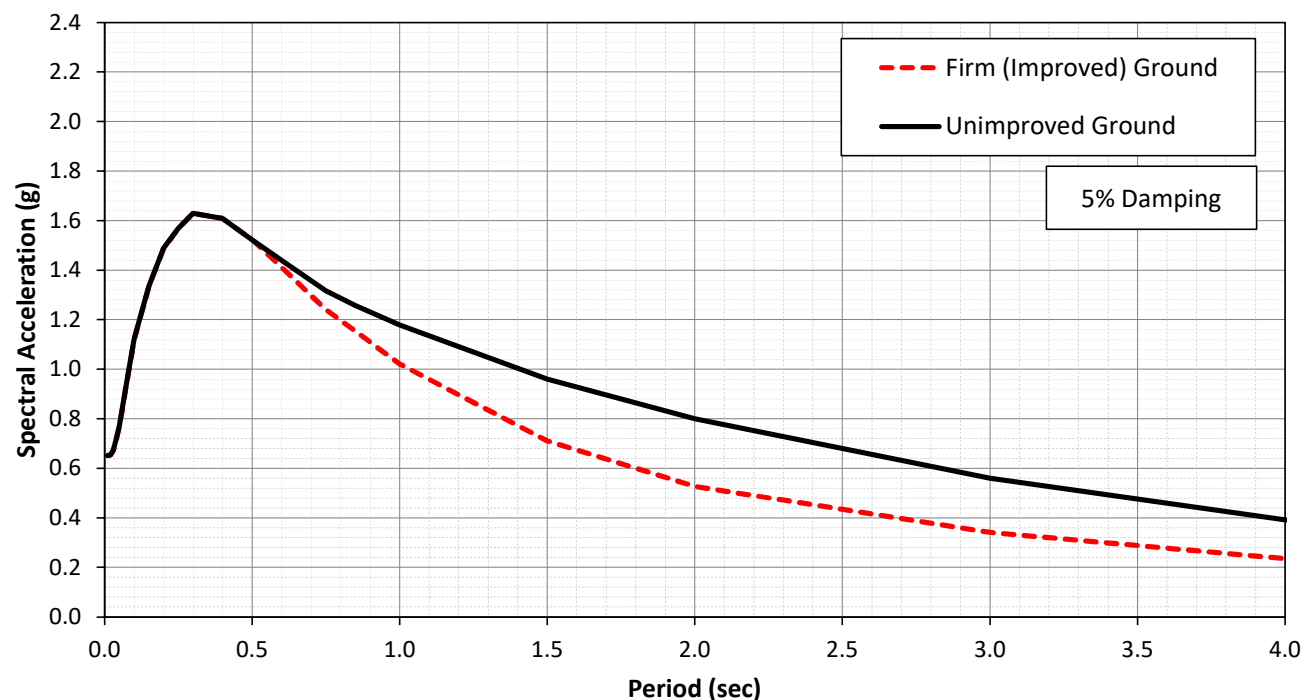
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MCE_R Response Spectrum Developed Based on ASCE 7-22 for Unimproved Ground

Figure 5-2



Period (sec)	Firm (Improved) Ground DE ARS (g)	Unimproved Ground DE ARS (g)
0.010	0.651	0.651
0.020	0.654	0.654
0.030	0.673	0.673
0.040	0.717	0.717
0.050	0.771	0.771
0.075	0.948	0.948
0.100	1.121	1.121
0.150	1.334	1.334
0.200	1.489	1.489
0.250	1.569	1.569
0.300	1.630	1.630
0.400	1.609	1.609
0.500	1.523	1.523
0.600	1.411	1.440
0.750	1.241	1.317
0.850	1.154	1.257
1.000	1.021	1.178
1.500	0.711	0.960
2.000	0.527	0.800
3.000	0.342	0.560
4.000	0.235	0.392
5.000	0.176	0.288
7.500	0.096	0.152
10.000	0.059	0.088



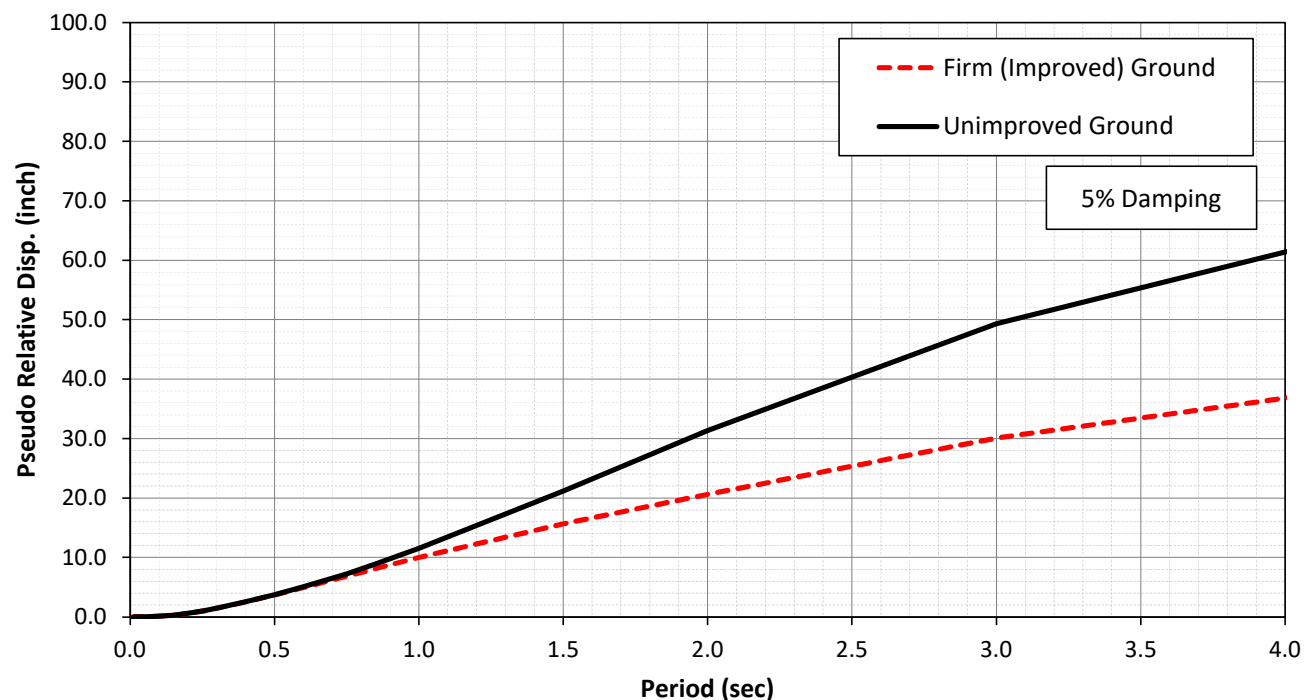
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Date: April 2026

Recommended DE Acceleration Response Spectra Developed Based on ASCE 7-22 For Firm (Improved) Ground and Unimproved Ground

Figure 5-3



Period (sec)	Firm (Improved) Ground DE ARS (inch)	Unimproved Ground DE ARS (inch)
0.010	0.001	0.001
0.020	0.003	0.003
0.030	0.006	0.006
0.040	0.011	0.011
0.050	0.019	0.019
0.075	0.052	0.052
0.100	0.110	0.110
0.150	0.294	0.294
0.200	0.583	0.583
0.250	0.960	0.960
0.300	1.436	1.436
0.400	2.520	2.520
0.500	3.726	3.726
0.600	4.971	5.074
0.750	6.831	7.249
0.850	8.161	8.891
1.000	9.995	11.531
1.500	15.665	21.141
2.000	20.621	31.320
3.000	30.110	49.330
4.000	36.811	61.388
5.000	43.066	70.471
7.500	52.853	83.684
10.000	57.421	86.131



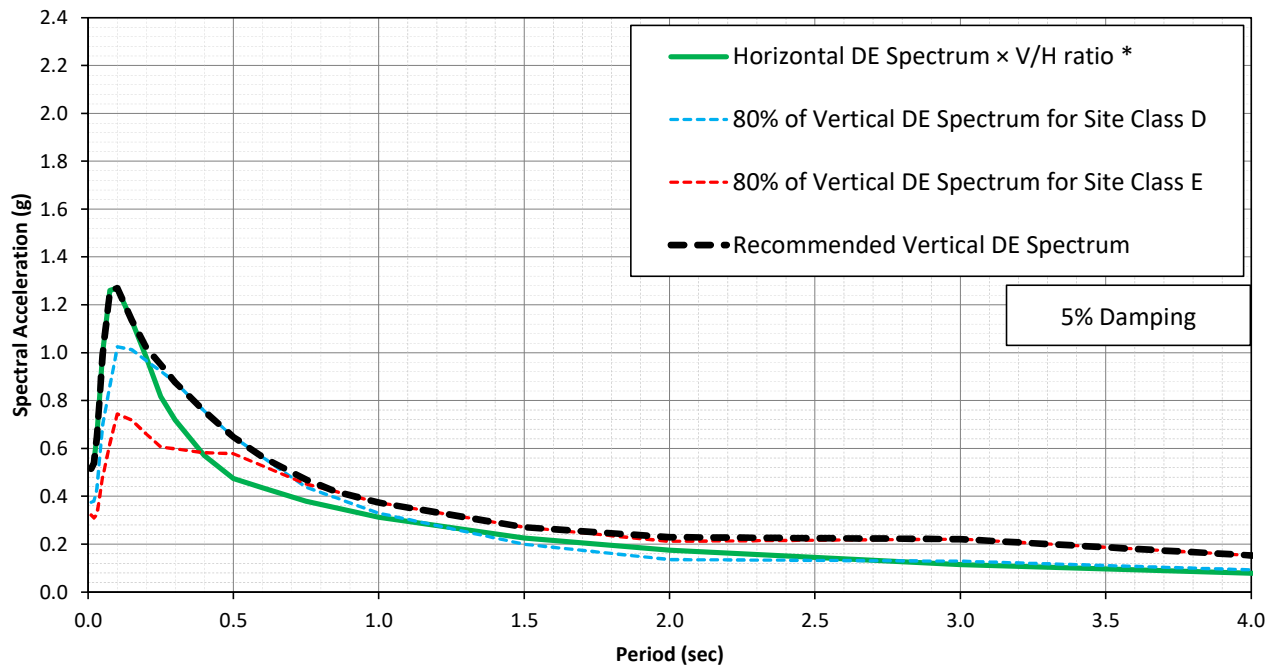
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Recommended DE Displacement Response Spectra Developed Based on ASCE 7-22 For Firm (Improved) Ground and Unimproved Ground

Figure 5-4



Period (sec)	Vertical to horizontal (V/H) spectral ratios	Horizontal DE Spectrum $\times$ V/H ratio *	80% of Vertical DE Spectrum for Site Class D	80% of Vertical DE Spectrum for Site Class E	Recommended Vertical DE Spectrum
T (sec)	-	Sa (g)	Sa (g)	Sa (g)	Sa (g)
0.01	0.942	0.515	0.375	0.323	0.515
0.02	0.981	0.539	0.380	0.310	0.539
0.03	1.145	0.647	0.431	0.325	0.647
0.04	1.349	0.813	0.564	0.403	0.813
0.05	1.535	0.995	0.697	0.480	0.995
0.08	1.581	1.260	0.865	0.623	1.260
0.10	1.348	1.270	1.025	0.744	1.270
0.15	1.021	1.135	1.013	0.718	1.135
0.20	0.796	0.979	0.966	0.660	1.020
0.25	0.629	0.816	0.924	0.606	0.950
0.30	0.538	0.719	0.877	0.599	0.877
0.40	0.436	0.570	0.756	0.583	0.756
0.50	0.382	0.473	0.648	0.578	0.648
0.60	0.381	0.435	0.564	0.527	0.564
0.75	0.378	0.379	0.438	0.452	0.470
0.85	0.379	0.352	0.395	0.420	0.420
1.00	0.379	0.312	0.330	0.374	0.374
1.50	0.392	0.225	0.200	0.271	0.271
2.00	0.410	0.174	0.136	0.213	0.230
3.00	0.417	0.114	0.129	0.222	0.222
4.00	0.422	0.079	0.093	0.154	0.154
5.00	0.422	0.059	0.069	0.113	0.113
7.50	0.408	0.031	0.037	0.060	0.060
10.00	0.377	0.017	0.023	0.035	0.035

* Following ASCE 7-22 Section 11.9, the horizontal DE spectrum was modified by dividing it by the maximum directionality factors proposed by Shahi and Baker (2014).



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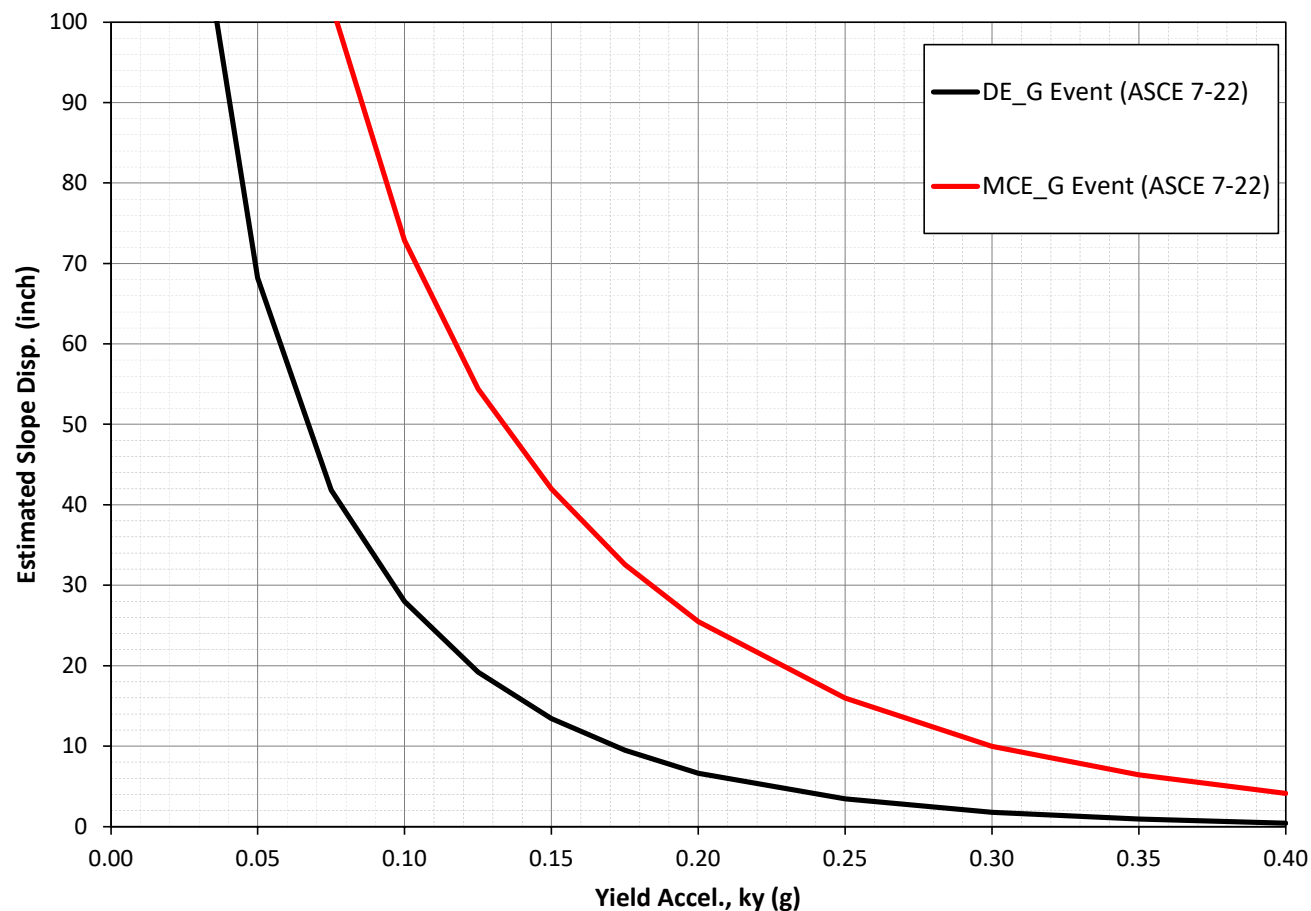
Addendum No. 1 to the 2020 Port-Wide Ground Motion Study Update, Port of Long Beach, California

EMI Project No: 23-150-2

Date: April 2026

Recommended DE Vertical Acceleration Response Spectrum Based on ASCE 7-22 For Firm (Improved) Ground and Unimproved Ground

Figure 5-5



Yield Accel., k_y (g)	Slope Disp., DE_G Event (inch)	Slope Disp., MCE_G Event (inch)
0.01	259	525
0.02	159	319
0.03	114	239
0.05	68.2	155
0.075	41.8	102
0.1	28.0	72.9
0.125	19.2	54.4
0.15	13.4	42.0
0.175	9.5	32.6
0.2	6.6	25.5
0.25	3.4	16.0
0.3	1.8	9.9
0.35	0.9	6.4
0.4	0.4	4.1

MCE_G : maximum considered earthquake geometric mean

DE_G : Defined as two-thirds of MCE_G .



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Recommended Newmark Displacement Curves for Site Screening for DE_G and MCE_G Events

Figure 5-6

6.0 LIMITATIONS

This Addendum to the 2020 Port-Wide Ground Motion Study Update Report was prepared by Earth Mechanics, Inc. (EMI) under a contract with WSP and is intended for the sole use by the Port of Long Beach (POLB) and by engineering consultants working on POLB projects located within the Long Beach Harbor District (LBHD). The POLB, WSP, and EMI have no responsibility for the use of this report by any other entities for their projects within the LBHD unless it is specifically required by the POLB.

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APPENDIX A PROBABILISTIC SEISMIC HAZARD ANALYSIS (PSHA)



Updated Probabilistic Seismic Hazard Analysis (PSHA) for Port of Long Beach (POLB) Study Sites

Final Report

Prepared for:

Earth Mechanics, Inc.

Prepared by:

Drs. Nick Gregor and Linda Al Atik

April 17, 2026

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1. Introduction

An updated probabilistic seismic hazard analysis (PSHA) study is performed for Site 1 – Navy Mole (West), Site 3 – Pier T, Site 5 – Pier A, and Site 8 – Pier E in the Port of Long Beach (POLB) area. These site locations are listed in Table 1 and plotted in Figure 1 along with the crustal faults in the vicinity.

These sites and the computed ground motions are expected to be associated with the engineering design of wharves, piers, and or other non-residential buildings with a general spectral period range for this collection of infrastructure in the range of 0.2 – 2.0 sec. Previous PSHA studies have been performed in the POLB area, and the methodology of this study is consistent with these previous calculations (Earth Mechanics, 2006, 2020, 2024). The results presented in this study are based on an assigned V_{S30} value of 450 m/sec consistent with the seismic provisions defined in ASCE 7-22 (ASCE, 2022) for the calculation of site-specific ground motions. These ground motions are anticipated to be used as input ground motions for the site-specific site response analysis to be performed separately.

Table 1. Site locations for the PSHA study.

Site	Longitude	Latitude
Site 1 – Navy Mole (West)	-118.24	33.743
Site 3 – Pier T	-118.237	33.753
Site 5 – Pier A	-118.239	33.772
Site 8 – Pier E	-118.213	33.76

The PSHA ground motions are developed following a standard PSHA methodology and the current state of knowledge and practice for the input models. The basic elements of a PSHA are shown in Figure 2 (Earthquake Engineering Research Institute, 1989). The seismic source characterization (SSC) and ground motion characterization (GMC) models constitute the inputs to the PSHA. The SSC model defines the earthquake source seismicity and geometry while the GMC model defines the ground-motion scaling as a function of the earthquake source parameters, propagation parameters, and local site conditions. The primary output of a PSHA is a set of seismic hazard curves for the ground motion parameters of interest from which uniform hazard spectra (UHS) are developed using equations given in McGuire (2004). A deaggregation of the seismic hazard using equations given in Bazzurro and Cornell (1999) is used to define controlling events (design earthquake scenarios) required to develop the vertical design spectra and design time histories. Note that design time histories are developed as part of this study.

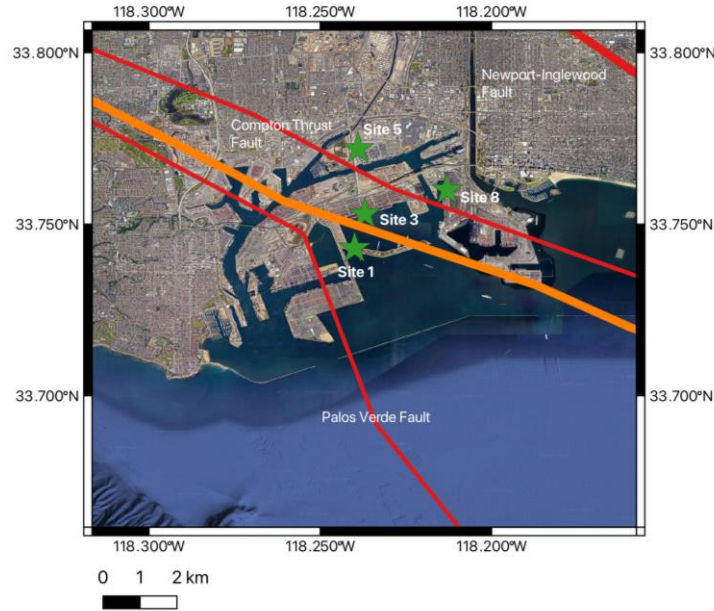


Figure 1. Location of Sites 1, 3, 5, and 8 in the POLB area used for the PSHA study and the surface projection of the fault traces from the UCERF3 (red lines) and Wilmington faults (orange line).

The primary SSC model implemented in this study is the Uniform California Earthquake Rupture Forecast, Version 3 (UCERF3) (USGS, 2013) which is recognized as the current state of knowledge for crustal seismic source characterization in California and is consistent with the SSC model used in ASCE 7-22. Given the more regional nature of the UCERF3 SSC model, the local Wilmington fault is not part of the crustal fault characterization of the UCERF3 model or the newer Earthquake Rupture Forecast (ERF23) (Field et al., 2024) SSC model used in the updated USGS national seismic hazard map calculations. However, given the close proximity to the POLB area, the recent characterization of the Wilmington fault (Wolfe et al., 2019, 2022) is also included as part of the SSC model for this calculation.

The current Next Generation Attenuation for Western US (NGA-West2) suite of ground motion models (GMMs) (Bozorgnia et al., 2014) are used in this study. The Al Atik and Youngs (2014) recommended epistemic uncertainty model for the NGA-West2 GMMs is also applied in the analysis.

The PSHA is computed for each site given an assigned primary average shear wave velocity in the top 30 m (V_{S30}) of 450 m/sec based on the seismic provisions of ASCE 7-22. In addition, the basin depth parameters (i.e., Z_1 and $Z_{2.5}$) required by the GMMs were evaluated based on 3D velocity models for southern California (Small et al., 2017) for nearby sites in the POLB area (Earth mechanics, 2024) and in the Port of Los Angeles (POLA) area (Earth Mechanics, 2025). Insights gained from these two studies were used to select Z_1 and $Z_{2.5}$ estimates for use in this study.

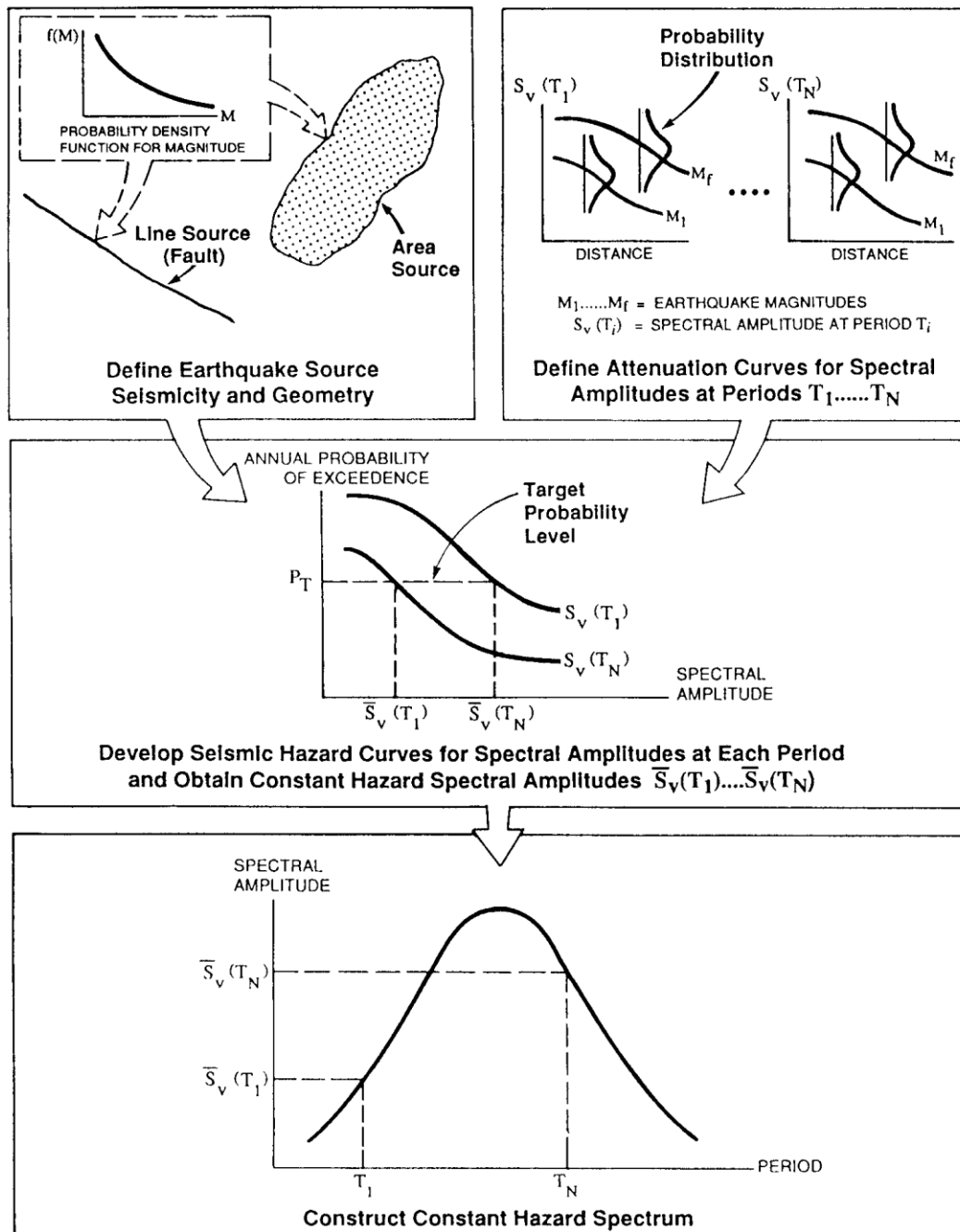


Figure 2. Schematic showing the elements of a probabilistic seismic hazard analysis (Source: Earthquake Engineering Research Institute, 1989).

As noted earlier, it is anticipated that additional one-dimensional (1D) site response analyses will be performed for site-specific soil columns developed separately from this PSHA study. For these 1D site response analyses, acceleration time histories will be developed as input ground motions based on the 450 m/sec V_{s30} parameter. The selection and development of these time

histories should be based on the results of this study (i.e., ground motions and deaggregation results) and are not presented in this report.

The PSHA is performed for the full range of spectral periods up to 10 sec (0.01 sec or peak ground acceleration PGA, 0.02, 0.03, 0.05, 0.075, 0.1, 0.15, 0.2, 0.25, 0.3, 0.4, 0.5, 0.75, 1, 1.5, 2, 3, 4, 5, 7.5, 10 sec). These calculations are for the RotD50 horizontal component of motion (Boore, 2010).

Given the close proximity of the Palos Verdes fault and other faults in the immediate region around the POLB area, multiple directivity models are implemented for the analysis. Given the spectral period range of interest (i.e., 0.2 – 2.0 sec) for this project, the behavior of these directivity models to impact longer spectral period ground motions (i.e., periods greater than about 0.5 sec), and the return period range of interest (i.e., less than 2,475 years), the impact from these directivity models is not expected to be significant. These directivity models have been integrated with the complex SSC model of UCERF3 including the rare but large magnitude events which occur from multiple segments connecting for a given rupture. Note that these directivity models are not included for the dip-slip Wilmington fault given its relative smaller contribution to the total hazard than the strike-slip Palos Verdes fault along with the understanding that these directivity models are more robust for strike-slip sources than for dip-slip sources. For the implementation of the directivity models, both an adjustment to the median ground motions and reduction in the aleatory sigma are applied.

Uniform hazard spectra (UHS) are developed for each site for 4 hazard levels corresponding to return periods of 72, 475, 975, and 2,475 years. Deaggregation results indicating the contribution from seismic sources binned as a function of magnitude and distances are computed for these four hazard levels and a selected number of spectral periods. These deaggregation results are developed for the horizontal component of motions without the inclusion of the directivity models. The deaggregation results are not expected to change significantly with the inclusion of directivity effects and are not computed nor presented for these cases including directivity.

For the defined hazard levels, the UHS are developed for each site for the average horizontal component without directivity, average component with directivity, fault normal component and fault parallel component of motions based on the application of the suite of directivity models.

The PSHA calculations are performed using the PSHA software HAZ45-CEC computer program (Al Atik et al., 2022, 2023). An earlier version of this computer program was validated for calculating seismic hazard by successfully passing the test cases developed as part of the Pacific Earthquake Engineering Research Center (PEER) PSHA code verification project (Hale et al., 2018). This validation study is described in Gregor and Al Atik (2017).

In addition to the horizontal component ground motion, vertical design spectra can be developed for all sites for the four return periods of 72, 475, 975, and 2,475 years. These vertical spectra should be developed using vertical to horizontal (V/H) models with input

parameters representative of controlling earthquake scenarios selected based on the deaggregation results. This report provides the recommended V/H ratios based on the selected scenario events for the four hazard levels. These V/H ratio values are applicable for all four site locations given their close proximity and should be applied to the average horizontal component without directivity.

In this report, we present an overview of the SSC and GMC models as implemented in HAZ45-CEC. The PSHA results are presented for each site in terms of mean hazard curves at select spectral periods (i.e., 0.01, 0.2, 1, and 3 sec). The uniform hazard spectra (UHS) are presented at the specified hazard levels for the assigned V_{S30} value of 450 m/sec. Digital files for selected spectral periods of the mean hazard curves for the horizontal component without directivity are provided electronically to allow for the risk adjustment coefficients following the seismic provisions of ASCE 7-22. Deaggregation plots are presented for the same selected spectral period values of 0.01, 0.2, 1, and 3 sec. V/H ratios that can be used for the development of the vertical design spectra are presented at the specified hazard levels for the assigned V_{S30} value of 450 m/sec.

2. Seismic Source Characterization Model

Tectonically, the POLB is located in the coastal area of the greater Los Angeles basin where the present-day tectonic stress is in a north-northeasterly compressional regime. The area contains basin bounding faults, dipping buried thrust faults and more vertically dipping strike-slip faults. As part of the USGS National Seismic Hazard Mapping program (NSHMP), the Uniform California Earthquake Rupture Forecast Version 3 (UCERF3) seismic source model (USGS, 2013) was developed for the entire state of California. This model, which is now over a decade old, incorporated previous regional SSC models (e.g., northern and southern California SSC models) to integrate into a complex SSC model that accounts for potential seismic events associated with both mapped and unmapped faults. One feature of the UCERF3 model that is different from previous models was the relaxation of strict fault segmentation boundaries. In the UCERF3 model, fault segments are allowed to join together forming larger ruptures (i.e., events with magnitudes greater than 8), although with a low probability of occurrence.

As part of the UCERF3 SSC model, a broad range of data was used to perform a grand inversion which estimates the long-term rate of occurrence of all earthquakes of magnitude 5.0 and larger. Both planar fault segments and gridded smooth seismicity point sources were considered in this grand inversion. Mathematically, this grand inversion is somewhat straightforward; however, based on the volume of input data and as importantly the number of logic tree branches (i.e., 1,440 logic tree branches) considered for the epistemic uncertainty (e.g., see Figure 3 of USGS, 2013), the grand inversion was performed on super computers. Two notable features of the UCERF3 SSC model are the removal of the over-prediction of earthquakes in the magnitude 6.5-7.0 range when compared to the historical seismicity catalogs and the potential for earthquake ruptures associated with multiple fault systems as have been observed in large crustal earthquakes.

Given the regional scale for the UCERF3 SSC model, it is not expected to fully contain any smaller scale site-specific seismic sources, especially those that were characterized after the development of the UCERF3 SSC model. It is expected that any of these potentially uncharacterized seismic sources would be included in the gridded seismicity distribution associated with the UCERF3 SSC model. This, however, assumes that any of these potentially unknown seismic sources have been seismically active in the duration of the historical seismicity catalog. This will be further discussed in the characterization of the Wilmington fault, which is not characterized specifically in the UCERF3 model.

As part of the on-going USGS NSHMP, an updated SSC model (ERF23) for California has been recently developed and published (Field et al., 2024). This model follows the same inversion methodology used in the UCERF3 development with the use of additional input models. For the area around the POLB, no new faults, such as the Wilmington fault, have been modeled for the newer ERF23 SSC model. Although this SSC model has recently been published, it has yet to be placed into practice or implemented within the ASCE building code framework and thus given the lack of any newly characterized faults in the area around the project, the PSHA performed in this study will be based on the implementation of the UCERF3 SSC model with the addition of the Wilmington fault. This also allows for consistency with the previous PSHA study (Earth Mechanics, 2024, 2025).

As part of the implementation of the UCERF3 SSC model for this study, only seismic sources associated with fault segments and gridded point sources located within a maximum distance of 300 km from each site are included in the PSHA study. Note that this maximum distance of 300 km is larger than is typically used (e.g., 200 km) for a given seismic source model in California. This cutoff distance is based on sensitivity studies for sites in California where the UCERF3 seismic source model indicated limited contributions from sources out to a maximum distance of 300 km. The use of a maximum distance of 300 km allows subsampling the full dataset of rupture scenarios while capturing the events expected to contribute to the seismic hazard at a given site location. This maximum distance used in the analysis is also within the acceptable distance range of the ground-motion prediction equations discussed later in this report.

2.1 UCERF3 Fault Sources

The UCERF3 SSC model consists of a total of 3,412 individual fault segments for the region around California. These individual segments were estimated based on a rupture length of approximately 7 km. Within the framework of the UCERF3 model, a minimum of at least two fault segments must rupture together to create an earthquake rupture scenario. In addition to this minimum number of rupture segments, multiple segments are allowed to rupture as part of a single earthquake scenario based on the assigned rules for multiple rupturing segments. Note that segments do not need to be continuous but must be within a close proximity of each other (e.g., about 5 km at any depth horizon) for multiple segments to rupture in a given scenario. This allowance for the joining of close but not continuous fault segments is a feature of the UCERF3 SSC that was not allowed in earlier versions of the UCERF SSC model.

Two fault models (FM3.1 and FM3.2) were developed for the UCERF3 SSC model and the recommended weights for these two models are 50% each. As part of the available data for the UCERF3 model, a combined dataset for both the FM3.1 and FM3.2 referred to as the “true mean solution” is used in this study. This combined dataset is provided to allow for the calculation of the mean hazard curves with a minimum set of ruptures and without the need to separately compute and combine the hazard results from FM3.1 and FM3.2 models. With this combined UCERF3 SSC fault model, there are a total of 1,634,466 individual earthquake rupture scenarios associated with combinations of the 3,412 individual fault segments for the entire region of California. For this study, the closest distance (rupture distance) from each site to the stitched fault segments associated with each fault rupture scenario is measured and scenarios with closest distance of less than 300 km from the site are included in the site-specific PSHA. Based on the cutoff distance of 300 km, the number of fault rupture scenarios included in the PSHA study for each site is listed in Table 2.

The fault traces of the individual UCERF3 fault segments within 300 km from sites 1, 3, 5, and 8 are plotted in Figures 3 through 6. As can be observed in these maps, the UCERF3 SSC model contains rupture scenarios in which multiple segments rupture together, therefore spanning a large area around and away from each site at distances greater than 300 km. Based on these long fault rupture lengths (e.g., a complete rupture of the San Andreas fault system), the associated magnitude for these scenarios can be large, however, their estimated rate of occurrence is generally low. The closest individual segment contained in the UCERF3 database to each of the sites is provided in Table 2. The Palos Verdes fault, a strike-slip fault with a dip angle of 90 degrees, is the closest to the four sites at a distance of 1.09 to 4.05 km.

Table 2. Number of fault scenarios and distance to closest UCERF3 fault segment for the site locations.

Site	Number of Fault Scenarios	Closest Fault Segment	Distance to Closest Segment [Palos Verdes], R_{rup} (km)
Site 1	1,121,865	Palos Verdes 10 (section ID = 1912)	1.09
Site 3	1,121,955	Palos Verdes 10 (section ID = 1912)	1.70
Site 5	1,129,005	Palos Verdes 10 (section ID = 1912)	3.07
Site 8	1,121,354	Palos Verdes 10 (section ID = 1912)	4.05

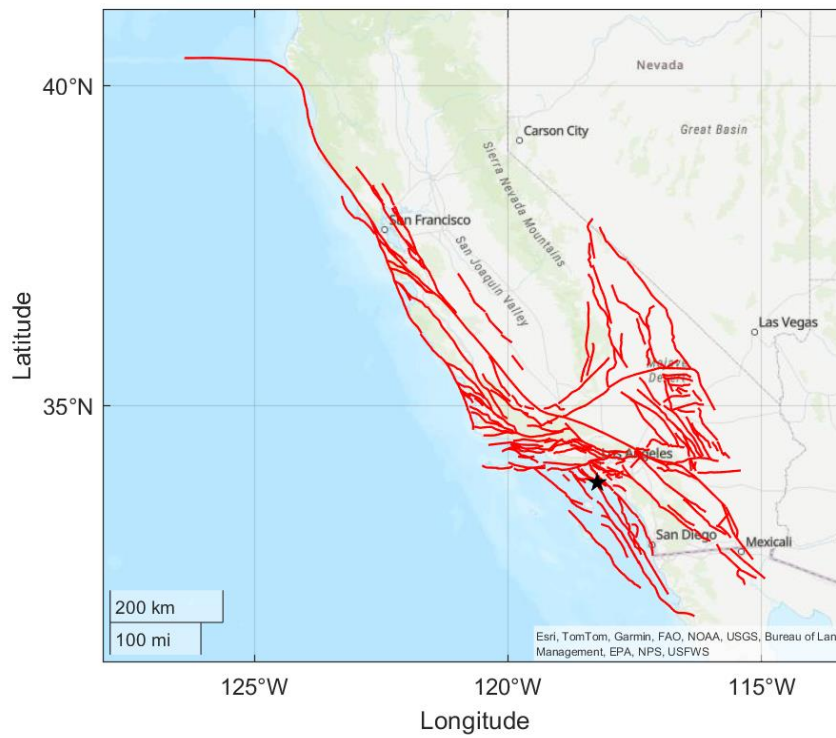


Figure 3. Regional map showing the UCERF3 fault segments (red traces) associated with all rupture scenarios within a closest maximum distance of 300 km from Site 1 (black star).

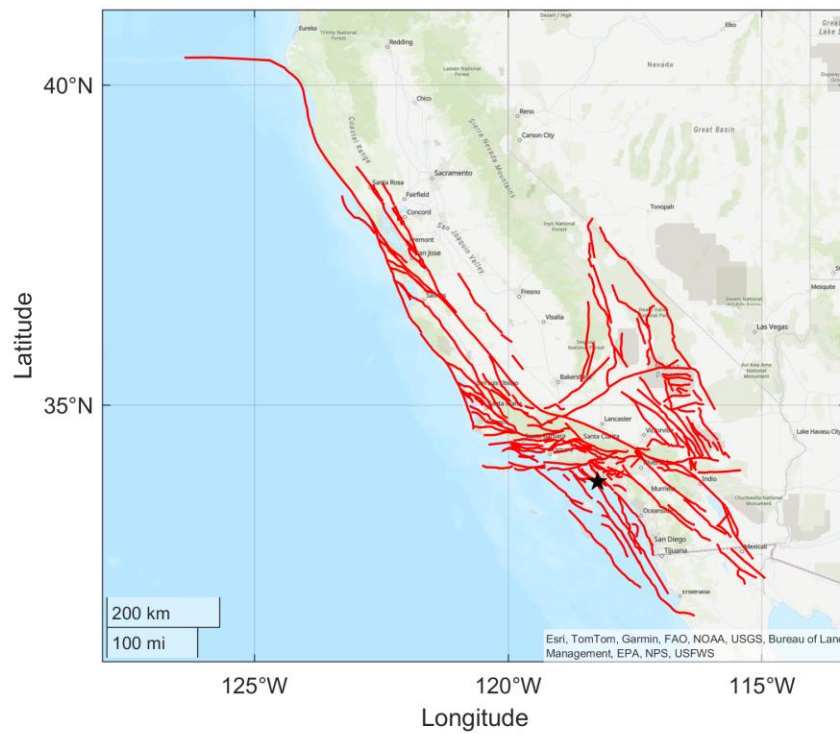


Figure 4. Regional map showing the UCERF3 fault segments (red traces) associated with all rupture scenarios within a closest maximum distance of 300 km from Site 3 (black star).

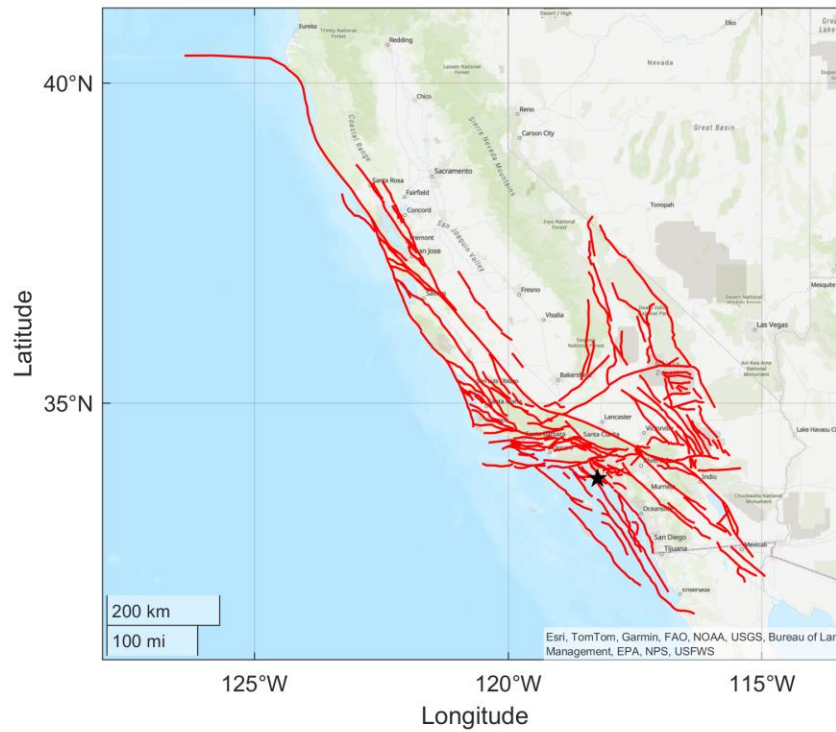


Figure 5. Regional map showing the UCERF3 fault segments (red traces) associated with all rupture scenarios within a closest maximum distance of 300 km from Site 5 (black star).

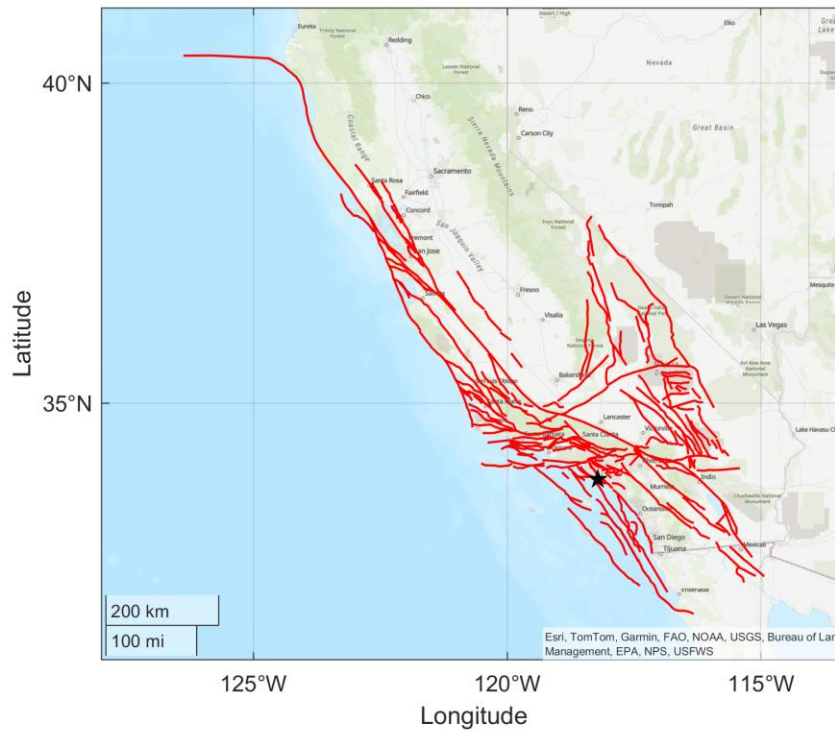


Figure 6. Regional map showing the UCERF3 fault segments (red traces) associated with all rupture scenarios within a closest maximum distance of 300 km from Site 8 (black star).

A summary of the UCERF3 mean slip rates from a selection of the closest faults to the site locations and other more active faults in the greater Southern California are listed in Table 3. Note, however, that these mean slip rates from the UCERF3 database are estimated based on the grand inversion and segmentation grouping of fault systems but are not used in the traditional method of performing a PSHA where the magnitude recurrence of a fault is estimated based on the slip rate and an assumed magnitude recurrence relationship. The average closest rupture distance R_{rup} from each parent fault to the four sites is listed in Table 3 for the significant fault sources.

Table 3. Mean UCERF3 slip rates for selected faults in the immediate area and regional faults.

Fault	Average Closest Distance, R_{rup} (km)	UCERF3 Mean Slip Rate (mm/yr)
Palos Verdes	2.48	2.28
Newport/Inglewood	7.53	1.22
Compton Thrust	5.35	0.82
San Pedro Basin	28.25	0.77

Elsinore (Glen Ivy)	59.90	6.23
San Andreas (Mojave S.)	83.98	24.85
San Jacinto (San Bernardino)	87.88	8.16

Based on the selected scenario fault ruptures within 300 km from each site, the summed annual rate of earthquakes as a function of magnitude is shown in Figures 7 through 10 for sites 1, 3, 5, and 8. Note that for the cut off distance of 300 km, approximately 69% of the total scenarios from the UCERF3 seismic source model are included in the selection for each of the three sites. The annual rates are plotted for all distances (red line) and for four distance bins.

For sites 1, 3, 5, and 8, Figures 7 through 10 indicate that the largest contribution to the total rates of scenario fault ruptures is primarily from scenarios with distance of 50 to 100 km for magnitude greater than 7.8 and greater than 100 km range for smaller magnitudes. Note that these observations for the binned rates showing a larger contribution from more distant sources (i.e., greater than 100 km) do not indicate an expected larger contribution to the hazard at the site from these more distant sources since the attenuation and estimation of ground motions is not considered in these comparison figures. The distance bin sampling which is not uniform and the regional faults in Southern California would lead to the expectation of a larger annual rate for these more distant bins given the larger number of seismic sources.

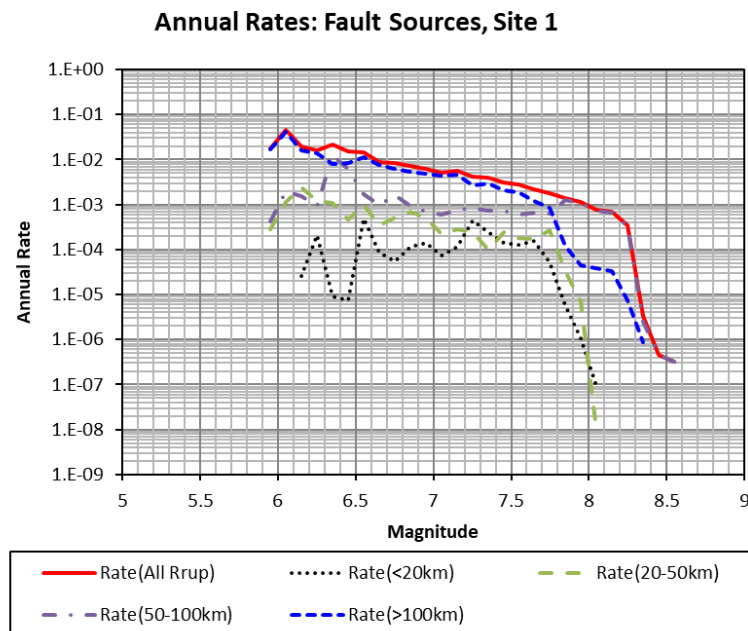


Figure 7. Cumulative annual rate of earthquakes from the UCERF3 fault sources within 300 km from Site 1.

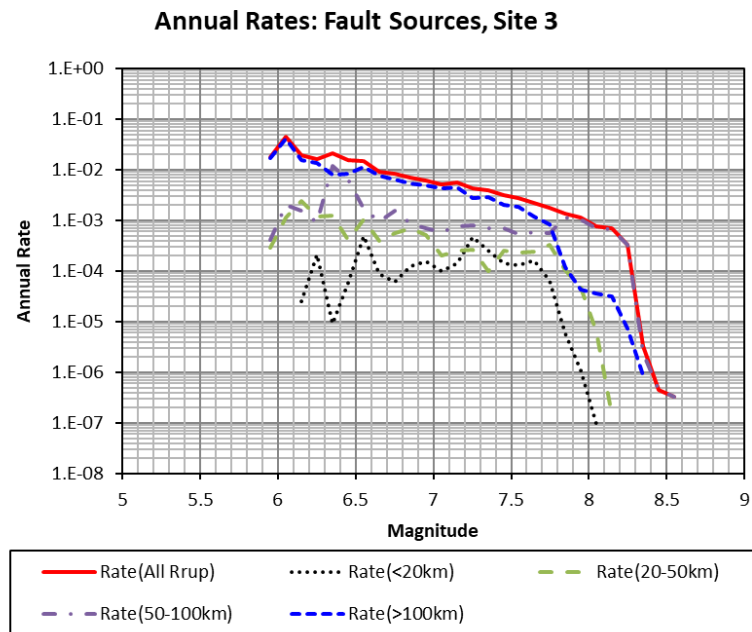


Figure 8. Cumulative annual rate of earthquakes from the UCERF3 fault sources within 300 km from Site 3.

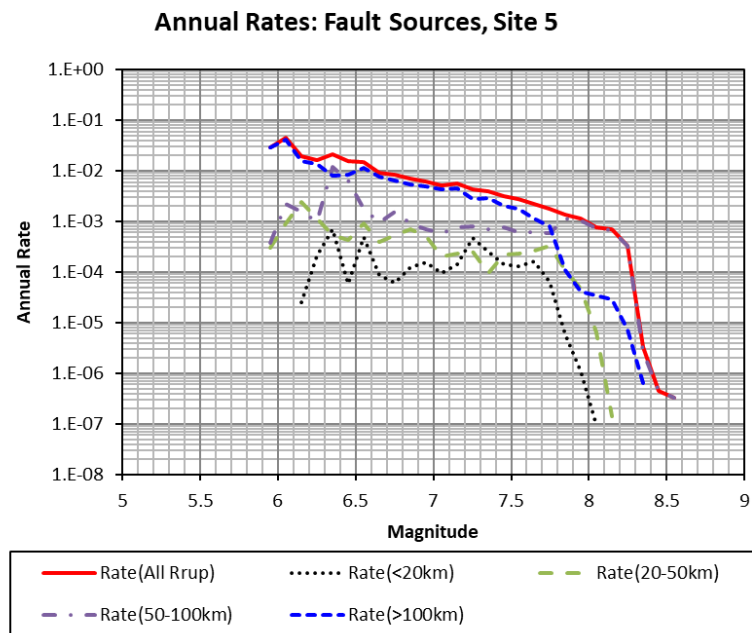


Figure 9. Cumulative annual rate of earthquakes from the UCERF3 fault sources within 300 km from Site 5.

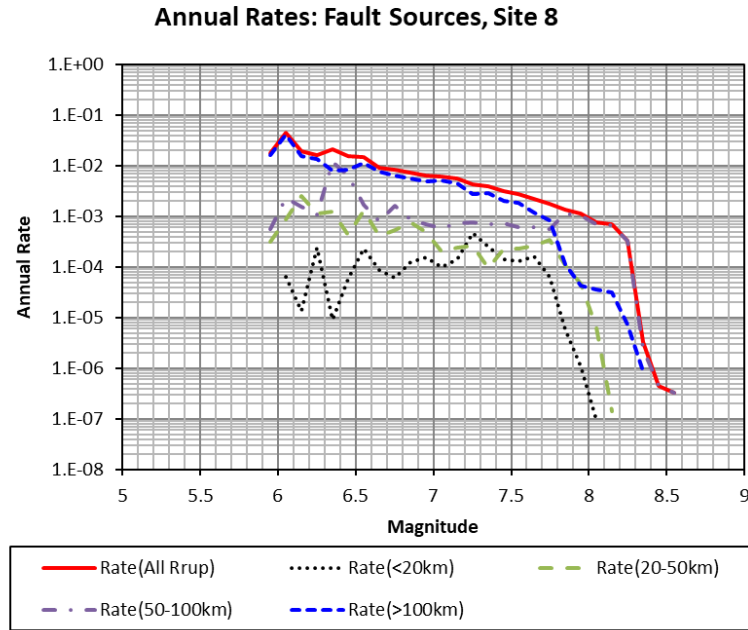


Figure 10. Cumulative annual rate of earthquakes from the UCERF3 fault sources within 300 km from Site 8.

Given the complexity of the UCERF3 source model with ruptures consisting of multiple individual rupture segments, there are several implementation steps that are used in the PSHA calculation. For example, for UCERF3 rupture scenarios in which multiple fault segments are included each with potentially different dip angles, a weighted-average dip angle is computed. This average dip angle is calculated based on the area-weighted dip angles for the individual fault segments relative to the total area of the entire rupture scenario (total area of all associated segments). Similarly, the average depth-to-top of rupture was calculated based on the area-weighted average of the depth-to-top of rupture of the individual fault segments associated with a particular rupture. For the distance calculation, the rupture distance (R_{rup}) and the Joyner-Boore distance (R_{jb}) are based on the closest segment to the site for a given rupture scenario. The other distances (R_x and R_{y0}) are based on the stitched segments for a given scenario using the area-weighted average depth to top and bottom of rupture and the average dip angle.

2.2 UCERF3 Gridded Seismicity

For the UCERF3 gridded point sources, a standard approach in analyzing and smoothing the historical earthquake catalog was employed. Gridded point source locations are defined at 0.1x0.1 degree latitude and longitude intervals and the UCERF3 SSC model provides a weighting scheme for each defined point location for the strike-slip, reverse, and normal earthquake mechanisms. These fault mechanism weights are used with the GMMs when estimating the ground motions from the grid point sources.

For the implementation of the UCERF3 gridded source model, distance corrections to account for finite rupture dimensions are computed based on the modeling of virtual faults centered at each grid point. For this distance correction approach, three virtual faults are considered: a vertical strike-slip fault, and reverse and normal dipping faults with a dip angle of 50 degrees. For the two dipping fault cases, both the hanging wall and footwall cases are considered with equal weights between the two cases. To account for the potential strike orientation of these virtual faults, three azimuthal orientations of perpendicular, parallel, and rotated by 45 degrees related to the site location are considered.

The number of gridded UCERF3 point sources within the cutoff distance of 300 km from sites 1, 3, 5, and 8 is 2,112, 2,114, 2,124, and 2,127 grid point sources, respectively. Similar to the UCERF3 fault sources, the cumulative annual rate of earthquakes from gridded sources versus magnitude is shown in Figures 11 through 14 for sites 1, 3, 5, and 8. The annual rates are shown for all distances (red line) and for four different distance bins and are very similar for the four sites given their proximity to each other.

For the gridded sources, the largest contribution to the total rates of gridded scenarios is coming from the grid points with distances greater than 100 km from the site. This largest contribution from the largest distance bin is expected based on the number of grid points which fall within each distance bin. As an example, for Site 8, the total number of grid points of 2,127 are distributed as 13 for distances less than 20 km, 64 for distances of 20 – 50 km, 230 for distances of 50 – 100 km, and 1,820 for distances greater than 100 km. However, this does not indicate that the more distant grid points will control the seismic hazard at the site since the attenuation and estimation of ground motions is not considered in these comparison figures. Comparing the cumulative annual rates of earthquakes from fault sources and gridded sources for the site, we note that the fault rupture scenarios have higher annual rate of occurrence than the gridded sources earthquakes for magnitude larger than about 6.25.

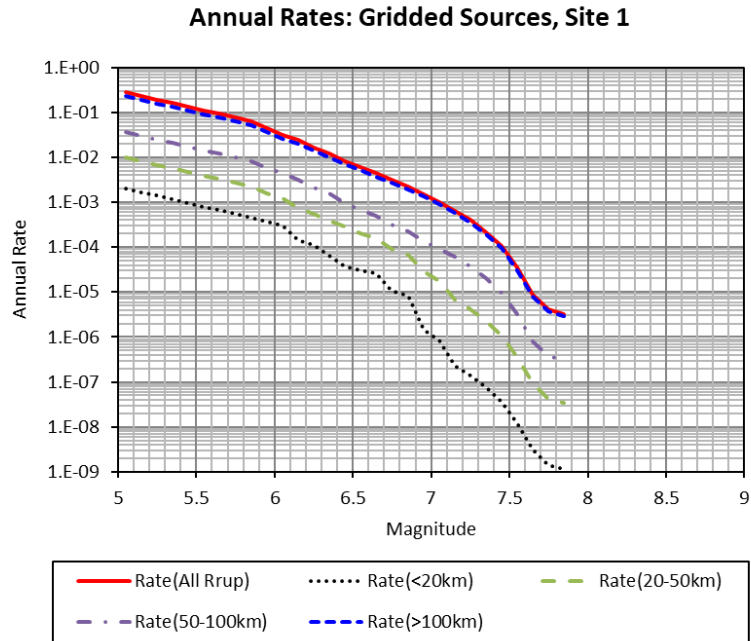


Figure 11. Cumulative annual rate of earthquakes from the UCERF3 gridded sources within 300 km from Site 1.

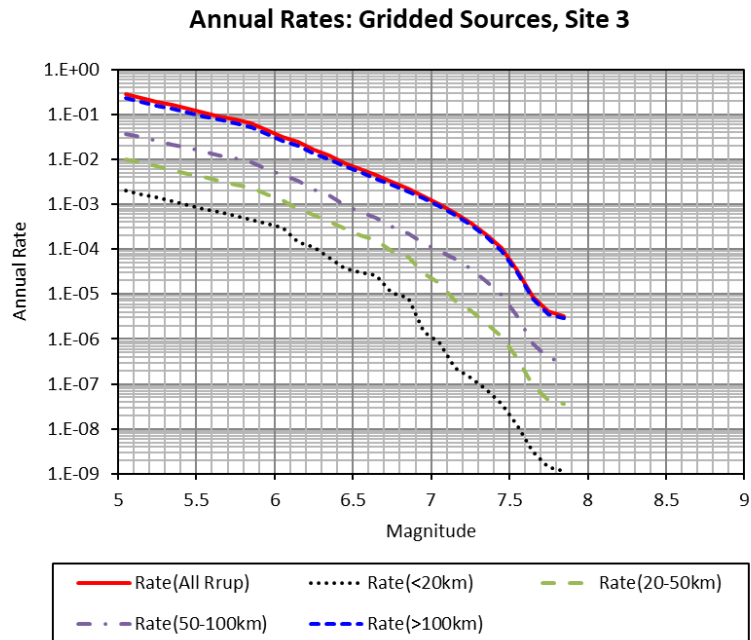


Figure 12. Cumulative annual rate of earthquakes from the UCERF3 gridded sources within 300 km from Site 3.

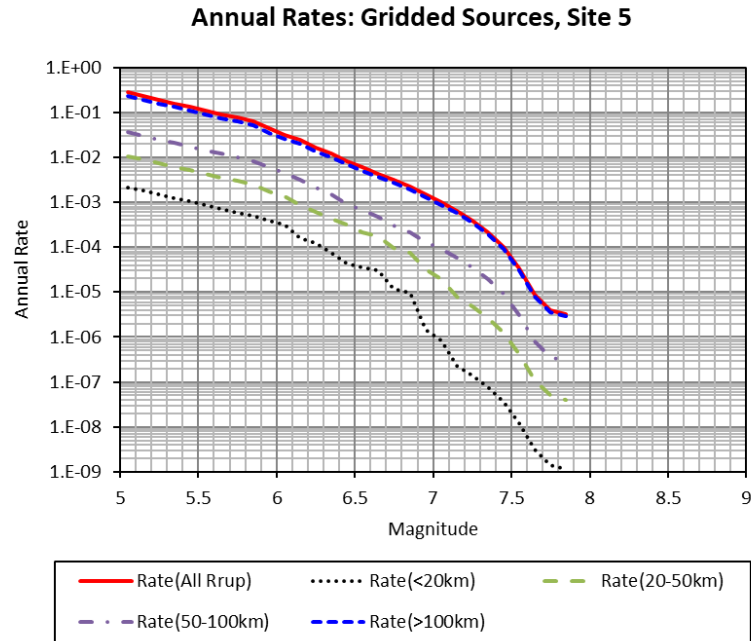


Figure 13. Cumulative annual rate of earthquakes from the UCERF3 gridded sources within 300 km from Site 5.

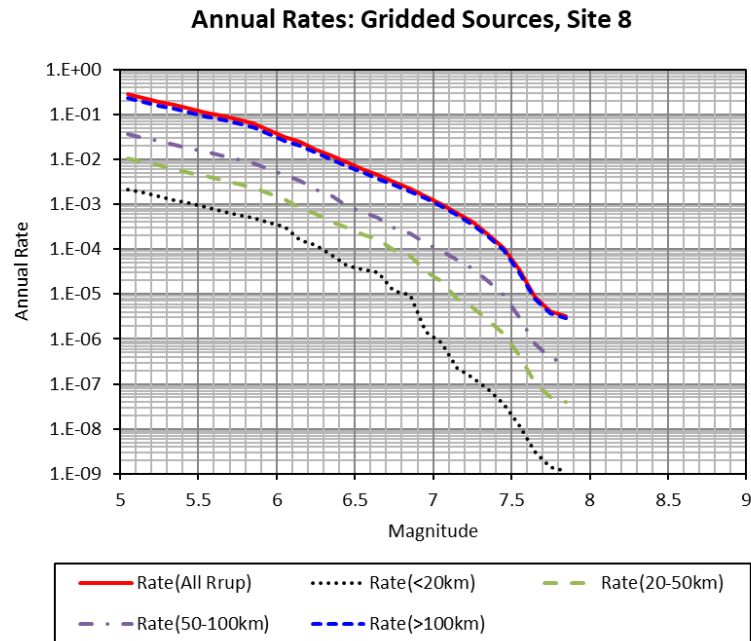


Figure 14. Cumulative annual rate of earthquakes from the UCERF3 gridded sources within 300 km from Site 8.

2.3 Wilmington Fault Characterization

Wolfe et al. (2019) proposed that the Wilmington fault is active and should be considered for seismic hazard studies in the Los Angeles region based on their analyses of 2D and 3D seismic reflection surveys, petroleum water wells, and recent ground water aquifers in the Los Angeles basin. Estimate of the slip rate for the preferred Wilmington fault is ~ 0.16 mm/yr (Wolfe et al., 2019) which is lower than the mean slip rates for the faults in the immediate area of the project and significantly lower than the more active regional faults in Southern California. As was noted earlier, the Wilmington fault is not considered as a planar fault source in either the UCERF3 or ERF23 SSC models. The inferred projected surface trace of the fault is shown in Figure 15 (taken from Figure 2 of Wolfe et al., 2019) and is also plotted in Figure 1 along with the locations of the sites. Wolfe et al. (2019) places the top of the buried fault at a depth of 1.25 km with the fault dipping to the northeast. This places site 1 on the footwall of the Wilmington fault and sites 3, 5, and 8 on the hanging wall.

The fault thickness, as characterized in Wolfe et al. (2019), is constrained to be 12 km given the geometry of the other dipping faults in the area and based on the constraint that the Wilmington fault does not cut across these other faults at depth. More recently, Wolfe et al. (2022) suggests that the presence of the Wilmington fault led to the formation of the restraining bend of the Palos Verdes fault which is observed in the change in strike of the Palos Verdes fault as it comes onshore just west of the POLB area.

It should also be noted that a summary of slip rates for the Palos Verdes fault is provided in Wolfe et al. (2022) study (i.e., see Table 1 of Wolfe et al., 2022). However, that study did not independently develop these slip rate estimates for the Palos Verdes fault. As noted in Wolfe et al. (2022) these slip rates range from 1.1 – 5.9 mm/yr based on the minimum and maximum values from studies published between 1994 and 2015. In comparison the range in slip rates for the Palos Verdes fault from the UCERF3 SSC model is 2.16 – 3.49 mm/yr. In reviewing these previously published values, there is a reduction in the overall range in slip rates from before UCERF3 and after (i.e., before and after 2013). The range from the cited studies post-2013 is 1.1 – 3.08 mm/yr which is more consistent with the range of slip rates from the UCERF3 model. The range from the pre-2013 studies are 1.8 – 5.9 mm/yr indicating a reduction of the estimated slip rates for the Palos Verdes fault over the last 30 years. Given the publication dates for the pre-2013 studies, it is assumed that those studies and results would have been considered for the development of the UCERF3 SSC model and the slip rates from the more recent studies are consistent with the slip rates in the UCERF3 SSC model for the Palos Verdes fault.

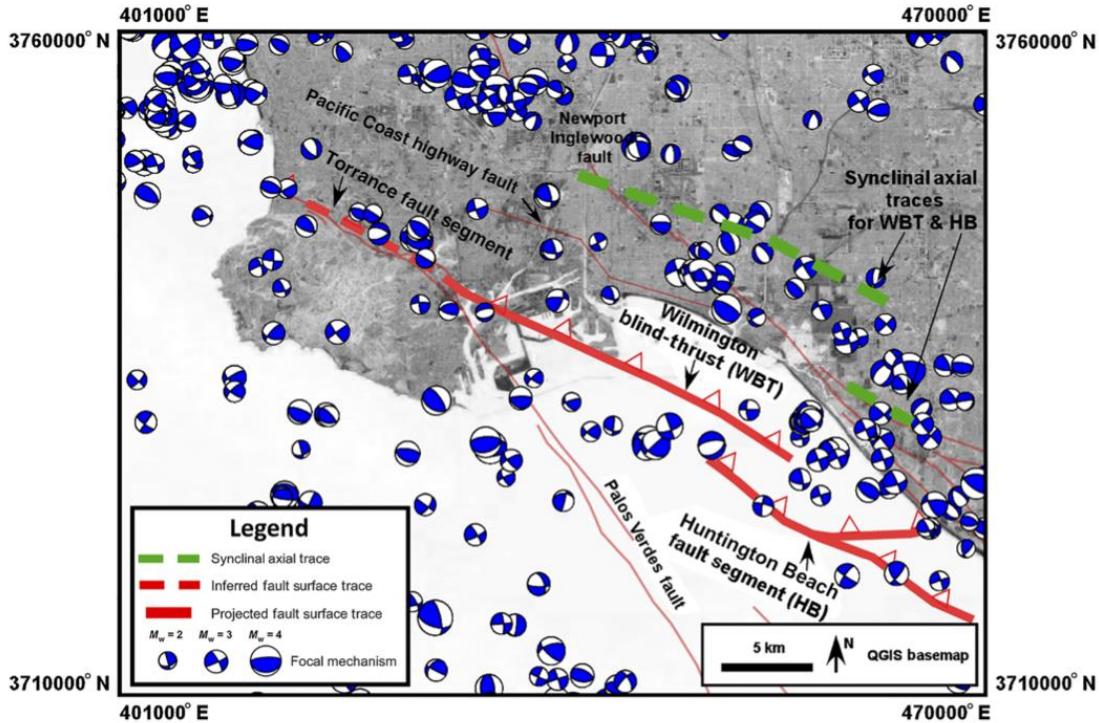


Figure 15. Regional map showing inferred projected surface fault trace for the Wilmington blind thrust fault. (Taken from Figure 2 of Wolfe et al., 2019).

Wolfe et al. (2019) characterized multiple potential rupture scenarios for the Wilmington fault (i.e., see Table 2 of Wolfe et al., 2019). Specifically, ruptures are estimated for the main Wilmington blind-thrust (WBT) segment with a preferred dip angle of 53 degrees and a minimum and maximum dip angle of 50 and 58 degrees, respectively. Additional ruptures are estimated for combinations of the WBT segment and the Torrance segment, Huntington Beach (HB) segment, and all three segments together. Note that individual ruptures of the Torrance and Huntington Beach segments were not characterized in the Wolfe et al. (2019) study.

For each of these rupture scenarios, maximum magnitudes were estimated based on the rupture area along with a range in recurrence intervals for each rupture scenario. These recurrence intervals ranged from 3,215 years to 6,535 years for the different rupture scenarios. Although recurrence intervals were provided for the different rupture scenarios, Wolfe et al. (2019) did not provide quantitative estimates for a segmentation model of the Wilmington fault system. To fully incorporate the Wilmington fault into the PSHA study, a logic tree is developed based on the model presented in Wolfe et al. (2019) which is summarized in Table 4 to account for the potential relationship between the rupture scenarios (i.e., they are not interpreted to be independent sources).

The first column describes the potential segmentation of the Wilmington fault system. Given the review of the Wolfe et al. (2019) study and the lack of a segmentation model, a weight of

only 0.1 is assigned to the full rupture of all three segments (i.e., Torrance through to the Huntington Beach segment). The remaining 0.9 is assigned to the rupture scenarios from Wolfe et al. (2019). In addition, given the higher focus on the main segment of the Wilmington fault, the segmentation model assigns a weight of 0.6 for a combined weight of 0.54. The weights for the other two rupture scenarios which include the Wilmington fault are both assigned weights of 0.2 for a combined weight of 0.18 for each case.

For the main Wilmington fault rupture, Wolfe et al. (2019) provides estimates of dip angle values in the form of preferred and minimum and maximum. In this study, the preferred value is assigned a weight of 0.63 with the upper and lower dip angles being assigned a weight of 0.185. The estimated maximum magnitudes based on the different rupture areas are listed in Table 4 along with the three discrete recurrence intervals in years. These maximum magnitude values are taken directly from Wolfe et al. (2019) and the three recurrence intervals are based on the upper, lower, and average values from the range given in Wolfe et al. (2019). No additional uncertainty is placed on the maximum magnitudes to be consistent with the Wolfe et al. (2019) model. For the three recurrence intervals, each value is assigned an equal weight of 1/3 given that the Wolfe et al. (2019) study only provides a range of recurrence intervals. Each rupture scenario is modeled with a characteristic magnitude probability density function with a b-value of 0.8.

The Wilmington fault is considered as an additional seismic source to the UCERF3 seismic source model. Given this additional seismic source without the consideration of any reduction or modification of the UCERF3 seismic source model, there is a potential that the seismic hazard and results may be over-estimated based on double counting from the seismic sources in this immediate area. However, the use of the assumed characteristic magnitude distribution will limit this potential conservatism given that any expected smaller magnitude events associated with the Wilmington fault would not be modeled and would be assumed to be included in the UCERF3 background seismic source. As will be shown later in this report, the overall contribution to the total hazard from the Wilmington fault is not significant and the incorporation of more details in the overall logic tree is not as critical and the adopted and interpreted Wilmington SSC model can be considered sufficient for this PSHA study.

Table 4. Interpolated and adopted logic tree for the Wilmington fault based on the Wolfe et al. (2019) characterization.

Segmentation	Dip	Magnitude	Recurrence Intervals (years)
Wilmington Fault (WF) (0.54)	50.0 (0.185)	6.4 (1.0)	3675 (0.33), 4202 (0.34), 4730 (0.33)
	53.0 (0.63)	6.4 (1.0)	3490 (0.33), 3990 (0.34), 4490 (0.33)
	58.0 (0.185)	6.3 (1.0)	3215 (0.33), 3677 (0.34), 4140 (0.33)
Torrance+WF (0.18)	53.0 (1.0)	6.6 (1.0)	4295 (0.33), 4912 (0.34), 5530 (0.33)

WF+Hungtington Beach (HB) (0.18)	53.0 (1.0)	6.6 (1.0)	4175 (0.33), 4770 (0.34), 5365 (0.33)
Torrance+WF+HB (0.1)	53.0 (1.0)	6.8 (1.0)	5080 (0.33), 5807 (0.34), 6535 (0.33)

3. Ground Motion Characterization Model

The other important input model needed for a PSHA study is the Ground Motion Characterization (GMC) model. As part of this full model, potential GMMs should be evaluated based on their development, application, and behavior for the expected controlling events. The current state of practice for crustal earthquakes is the application of the Next Generation Attenuation for Western US (NGA-West2) GMMs. In total there are five GMMs developed as part of the project and four are selected for use in this study. Note that the Idriss (2014) model was not used in the previous PSHA study (EMI, 2024) given the assigned V_{S30} value of 300 m/sec which is less than the minimum value of 450 m/sec recommended for this GMM. Although the V_{S30} value of 450 m/sec is within the applicable range for the Idriss (2014) model, it was not included to maintain consistency with the previous study in terms of the selected GMMs. The four models used are: Abrahamson et al. (2014) (referred to as ASK), Boore et al. (2014) (referred to as BSSA), Campbell and Bozorgnia (2014) (referred to as CB), and Chiou and Youngs (2014) (referred to as CY). These models are defined for the RotD50 horizontal component (Boore, 2010) of ground motion measure which corresponds to the 50th percentile of the response spectra over all rotation angles. Equal weights of 0.25 are applied to each of the four NGA-West2 GMMs.

Because the NGA-West2 GMMs were developed in a collaborative effort with interactions and exchange of ideas among the developers, the NGA-West2 developers indicated that additional epistemic uncertainty should be incorporated into the median ground-motion estimation from their GMMs. The additional epistemic uncertainty model of Al Atik and Youngs (2014) developed as part of the NGA-West2 project is implemented in this study. The Al Atik and Youngs (2014) epistemic uncertainty model is distance-independent but depends on magnitude, style-of-faulting, and spectral period. The logic tree for the ground-motion characterization model is shown in Figure 16.

For the ASK and CY models, the functional form of the models based on an “estimated V_{S30} ” value is implemented in this study given that the assigned V_{S30} are not based directly on measured data. Note that the difference between the estimated and measured V_{S30} flag only impacts the aleatory variability of two of the four GMM models (ASK and CY) but does not impact the median ground-motion estimates.

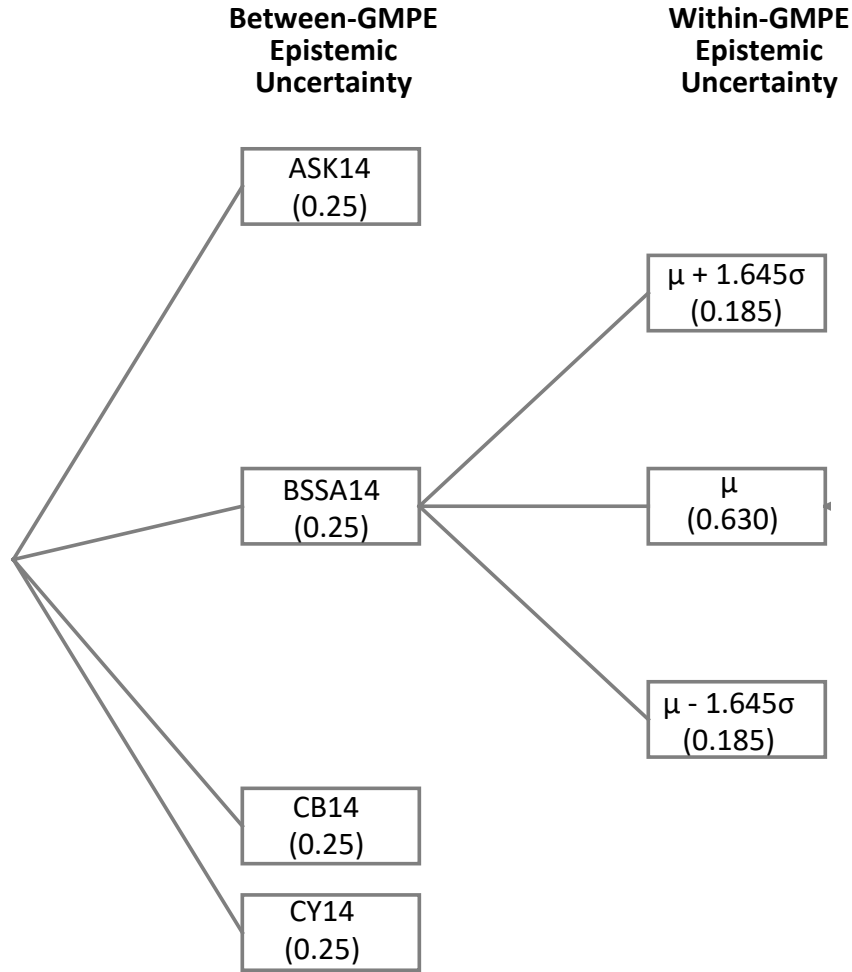


Figure 16. Ground-motion logic tree showing the different branches and associated weights; μ and σ are median prediction and epistemic standard deviation of the natural-logarithmic values of the ground-motion parameter of interest.

3.1 Basin Depth Parameters

In addition to the site response feature contained in each GMM parameterized with V_{S30} , each GMM attempts to estimate the ground motion response associated with deeper soil layering or basin structures. This parameterization is captured through the use of the depth to the 1 km/sec (Z_1) or 2.5 km/sec ($Z_{2.5}$) velocity horizons. The ASK, BSSA, and CY models use the difference between the site-specific Z_1 parameter and an estimated Z_1 value given a V_{S30} value while the CB model uses the $Z_{2.5}$ parameter. Thus, for implementation of these GMMs, estimates should be made for the depth to these velocity boundary layers.

The study sites and the POLB area are located within the larger Los Angeles basin, albeit near the western edge of the defined basin. As part of the metadata compilation for the NGA-West2

database, estimates of the Z_1 and $Z_{2.5}$ parameters were assigned to the strong ground motion stations. These estimates are typically not based on site-specific measurements due to the deep depths that would be required for site-specific studies. Given this limitation, the depth parameters are based on estimated values from regional uniform community velocity models (UCVM) that have been developed for various regions of California including the Los Angeles region (Small et al., 2017). These UCVMs represent a compilation of various geophysical and seismological studies into 3D velocity structure models that can be used for numerical simulation studies.

For the Los Angeles region, there are two main UCVMs (H and S4) as described in Small et al. (2017) that are applicable for the study area. A detailed evaluation of the shear-wave velocity (V_s) profiles and basin depth estimates was performed for nearby POLB sites in Earth Mechanics (2024) and for POLA sites in the recently completed Earth Mechanics (2025) study. These two studies observed significant differences in the V_s profiles obtained from the H and S4 models. For this reason and for consistency with the development of the NGA-West2 models, the H model was not considered for the estimation of the Z_1 and $Z_{2.5}$ parameters.

As noted earlier, for the three GMMs that use the Z_1 parameter, these models are function of the difference between a site-specific Z_1 value and a default Z_1 value given a V_{s30} . Both the ASK and CY models have default Z_1 - V_{s30} relationships that can be used to estimate the default Z_1 given an estimated V_{s30} value. Using the depth estimates from the S4 model resulted in delta Z_1 values that are negative in Earth Mechanics (2024, 2025). A negative delta Z_1 implies a reduction of the long-period ground motion to accommodate a shallower than average basin depth. In this study, we forego this potential long period reduction consistent with the Earth Mechanics (2025) study that was also performed for $V_{s30} = 450$ m/sec, and we use instead the default Z_1 in the analysis. The use of default Z_1 is consistent with the Earth Mechanics (2020) study performed for the same site locations with a different V_{s30} value. For V_{s30} of 450 m/s, the default average Z_1 of 300 m is used.

For the deeper $Z_{2.5}$ parameter which is used in the CB model, the values obtained from the S4 model for Earth Mechanics (2024, 2025) were deep in the range of 1.5 to 2.5 km. For the CB model, there is no additional basin response for the ground motions with $Z_{2.5}$ values between 1 – 3 km (i.e., 1000 to 3000 m). The default $Z_{2.5}$ value given an assigned V_{s30} value of 450 m/sec is 1,105 m. Hence, the default $Z_{2.5}$ value is used and the summary of the Z_1 and $Z_{2.5}$ values used in this study for V_{s30} of 450 m/sec is given in Table 5.

Table 5. Summary of V_{s30} , Z_1 and $Z_{2.5}$ values for the site locations used in this study.

Site	V_{s30} (m/sec)	Z_1 (m)	$Z_{2.5}$ (m)
1, 3, 5, and 8	450	300	1,105

3.2 Directivity Models

Given the close proximity of several faults in the area, a suite of directivity models is implemented. A brief discussion is presented in this report with additional details on the models and the implementation within the UCERF3 SSC model framework provided in Al Atik et al. (2022). These models are only applied to the UCERF3 faults (i.e., not the gridded source model) and are not applied to the Wilmington fault. The decision to not apply the models to the Wilmington fault is based on its relative lower characteristic magnitude range, the spectral period range of interest being 2 sec or less, the lesser contribution from the Wilmington fault to the total hazard and the general limitations and lack of robustness for the directivity models for dip-slip events.

A suite of directivity models has been developed as part of the NGA-West2 Project (Bozorgnia et al., 2014) and are documented in Spudich et al. (2013). These models are Bayless and Somerville (2013) (BS13), Chiou and Spudich (2013) (CS13), Spudich and Chiou (2013), Rowshandel (2013), and Shahi and Baker (2013). The Spudich and Chiou (2013) model based on the isochrone directivity parameter (IDP) is superseded with the CS13 model that is based on the direct point parameter (DPP) (Brian Chiou, personal communication). The NGA-West2 directivity models range in complexity with the BS13 model, which is an update to the Somerville et al. (1997) model, having the simplest formulation with few predictive parameters. On the other hand, the CS13 and the Rowshandel (2013) models are more complex to implement. All NGA-West2 directivity models as well as the Somerville et al. (1997) and Abrahamson (2000) models provide directivity adjustments for a known hypocenter location. Their implementation in hazard analysis requires the randomization of the hypocenter location over the rupture plane.

Following the development of the NGA-West2 directivity models, the Watson-Lamprey (2018) directivity model was developed to simplify the directivity implementation in hazard analyses by removing the need for hypocenter randomization over the rupture plane. This model is not an independent model but is based on the CS13 model. Bayless et al. (2020) (BSS20) updated their BS13 directivity model to include narrowband characteristics and better accommodate complex and multi-segment ruptures. The updated Bayless et al. (2020) model generally retains some of the computational simplicity of the BS13 model and uses both empirical ground-motion data and finite-fault simulations in the model development. Similarly, Rowshandel (2018) and Rowshandel (2020, personal communication) updated the Rowshandel (2013) directivity model. These updates involve improvements on the narrowband characterization, centering, as well as capturing rupture and slip heterogeneity effects.

The Somerville et al. (1997) and Abrahamson (2000) models were not considered for implementation in this study because these models were superseded by later models. A subset of models is selected from the set of NGA-West2 directivity models and subsequent models for implementation in this study (Al Atik et al., 2022). The selection of these models aims to

capture the epistemic uncertainty in modeling directivity effects. The subset of models considered consists of BS13, CS13, BSS20 and Watson-Lamprey (2018).

Incorporating near-field directivity effects in ground-motion models leads to a modification of the median ground-motion model and its aleatory variability (σ). For sites located in the vicinity of faults that can generate large-magnitude earthquakes, it is expected that the directivity adjustment would lead to an increased long-period median ground motion and a reduction in the ground-motion aleatory variability. This reduction in the aleatory variability is expected due to the inclusion of the additional explanatory term modeling directivity effects in the median model. The randomization of the hypocenter location on a rupture surface would lead to an increase of the variability in the ground motion.

While existing directivity models provide an adjustment to the median ground motion, reduction of the aleatory variability of the GMMs have been modest to non-existent. This has been generally attributed to the scarcity of data exhibiting directivity effects in the ground-motion datasets as well as the lack of azimuthal variations in the data. The updated model of BSS20 includes an adjustment to the aleatory variability which was implemented as part of this study. This same aleatory adjustment is also applied to the other directivity models used in this study.

As part of a California statewide PSHA study, Al Atik et al. (2022) evaluated the implementation of directivity models within the UCERF3 framework. One observation from that study was that the epistemic uncertainty in the characterization of directivity effects from the different directivity models is relatively large. Thus, this epistemic uncertainty warrants the inclusion of multiple directivity models. It was also observed that the results from the Watson-Lamprey (2018) model were not always consistent with the results from the CS13 model even though it was meant to be a representation of the CS13 model. One potential cause for these observed differences can be in the simplification of the rupture geometry in the Watson-Lamprey (2018) model compared to the CS13 model (Al Atik et al., 2022). For this reason, the CS13 model is selected over the Watson-Lamprey (2018) model.

Differences were also observed between the BS13 and the BSS20 models (Al Atik et al., 2022). While the BS13 model is broadband and predicts a relatively constant directivity adjustment factor for periods greater than 1 sec, the BSS20 model is a magnitude dependent narrowband model and has a gradual increase in the directivity adjustment with period. Both the BS13 and BSS20 models were included in the Al Atik et al. (2022) study following communications with the model developers. It was recommended that both models be included in addition to the CS13 model. The directivity models and assigned weights used in this study are based on the evaluation and conclusions in Al Atik et al. (2022) and are listed in Table 6. One difference compared to the Al Atik et al. (2022) study is the use of the aleatory variability reduction of BSS20 for all three directivity models. We note that this adjustment of the aleatory variability is

relatively small and has a small impact on the hazard results especially given the return period range of interest (i.e., 2,475 years and less).

Table 6. Summary of directivity models and assigned weights.

Directivity Model	Weight
CS13	0.50
BS13	0.25
BSS20	0.25

4. Probabilistic Seismic Hazard Analysis (PSHA)

4.1 Methodology

Probabilistic seismic hazard calculations were carried out using the computer program HAZ45-CEC. This PSHA program is based on the HAZ45 computer program (Abrahamson and Gregor, 2015) and follows a standard state of practice approach for probabilistic seismic hazard analysis. An earlier version of this PSHA program has successfully passed the validation test cases associated with the recent PEER PSHA Validation testing program (Hale et al., 2018).

A sigma truncation value of 8.0 is used for the PSHA. The minimum magnitude used in the analysis is 5.0. Mean Hazard curves are computed in this study for the following suite of spectral periods: PGA (0.01 sec), 0.02, 0.03, 0.04, 0.05, 0.075, 0.1, 0.15, 0.2, 0.25, 0.3, 0.4, 0.5, 0.75, 1.0, 1.5, 2.0, 3.0, 4.0, 5.0, 7.5 and 10.0 sec. Based on the GMMs used in the analysis, these mean hazard curves are defined for the RotD50 component (Boore, 2010). As stated earlier, given the potential significance of longer period design motions, the observed impact of rupture directivity on longer period ground motions, and the close proximity of several faults near the sites, rupture directivity models are implemented within the PSHA framework. These models are applied to the full UCERF3 seismic source database but are not applied to the Wilmington fault for the reasons stated earlier.

For the implementation of the directivity models using the UCERF3 source model, the necessary directivity parameters are computed for each scenario within a rupture distance of 80 km. Sources at distances greater than 80 km are not expected to contribute directivity adjustments even though some of the directivity models do not explicitly contain this distance tapering (Bayless, personal communication, 2016). This distance of 80 km is consistent with the distance limitations of the other directivity models presented in Spudich et al. (2013).

For the modeling of the potential locations of the hypocenters needed to estimate the directivity parameters, hypocenters are randomized in the along-strike and down-dip directions using a uniform distribution. Three hypocenter locations are used in the downdip direction. Along strike, three hypocenters are used if the fault length is less than or equal to 20 km, five are used if the length is between 20 and 50 km, and ten hypocenters are used for length greater than 50 km. The rate for a given scenario is equally divided among the number of randomized hypocenters for this scenario.

Based on the suite of mean hazard curves from the hazard analysis, uniform hazard spectra (UHS) are computed for the horizontal component of motion both with and without directivity for a range of return periods of 72, 475, 975, and 2,475 years. Estimates of the mean magnitude, distance, and epsilon values are computed for these four hazard levels and presented in this report for sites 1, 3, 5, and 8. Binned magnitude and distance contributions (i.e., deaggregation) to the hazard for selected spectral periods are computed and presented.

4.2 Site 1 Results

4.2.1 Site 1 Results without Directivity, $V_{s30} = 450$ m/sec

The mean hazard curves including the Wilmington fault for Site 1 are shown in Figures 17 through 20 for PGA and spectral periods of 0.2, 1, and 3 sec. For the longer spectral periods (i.e., 1 and 3 sec), these plots show the horizontal component without the inclusion of the directivity models. In these plots, individual hazard curves from the scenario fault ruptures from the UCERF3 faults, gridded sources, the Wilmington fault as well as the combined total hazard are presented. Hazard levels corresponding to the 475- and 2,475-year return periods are also plotted in the figures. For the short to intermediate spectral periods, the hazard is equally controlled by the UCERF3 grid and fault sources for hazard levels of about 100 to 200-year. For shorter return periods and the intermediate to short periods, the hazard is controlled by the gridded source. For longer return periods and as well longer spectral periods, the hazard is controlled by the UCERF3 fault sources. For all cases, the contribution from the Wilmington fault is less than from the other UCERF3 sources.

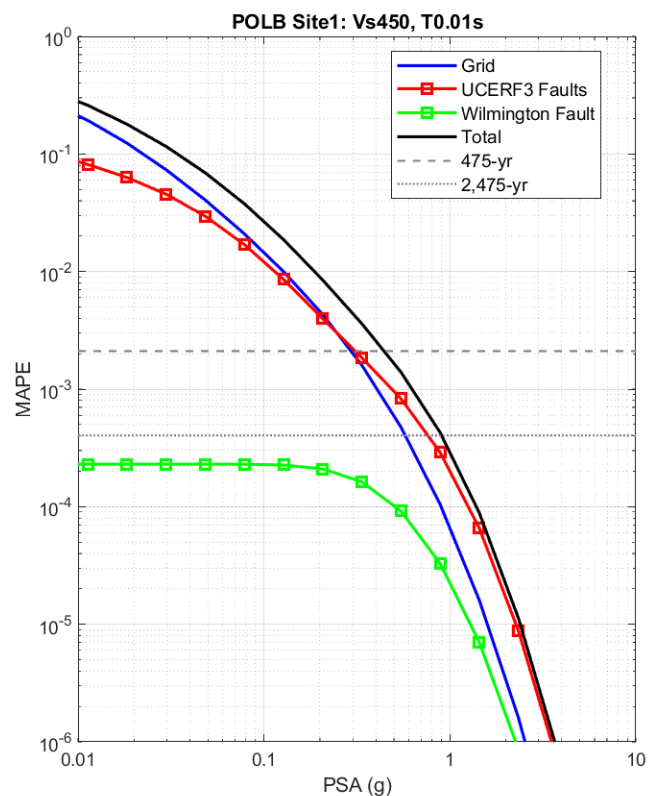


Figure 17. Mean horizontal component hazard curves from the UCERF3 gridded and fault sources, Wilmington fault, and total mean hazard for PGA for Site 1 for $V_{s30} = 450$ m/sec without directivity. MAPE refers to mean annual probability of exceedance.

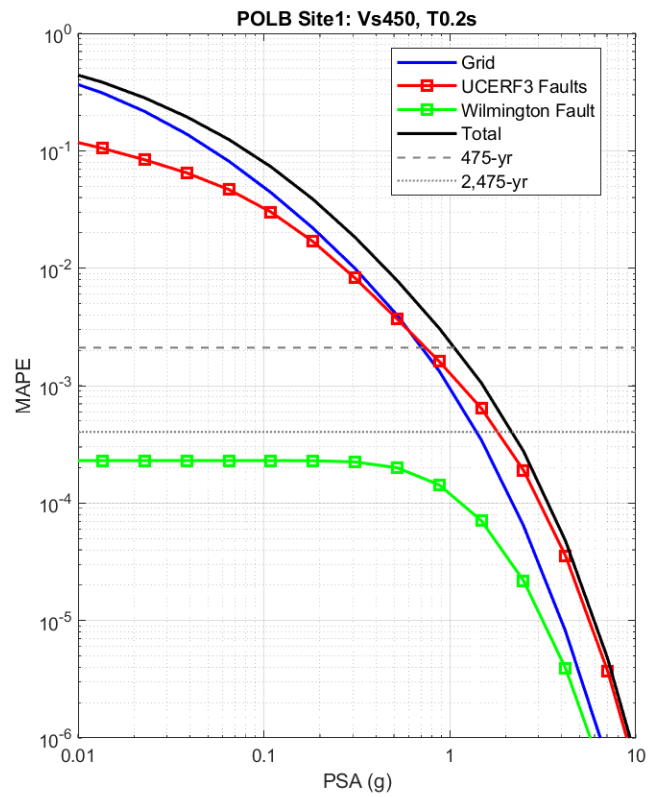


Figure 18. Mean horizontal component hazard curves from the UCERF3 gridded and fault sources, Wilmington fault, and total mean hazard for $T=0.2$ sec for Site 1 for $V_{S30} = 450$ m/sec without directivity. MAPE refers to mean annual probability of exceedance.

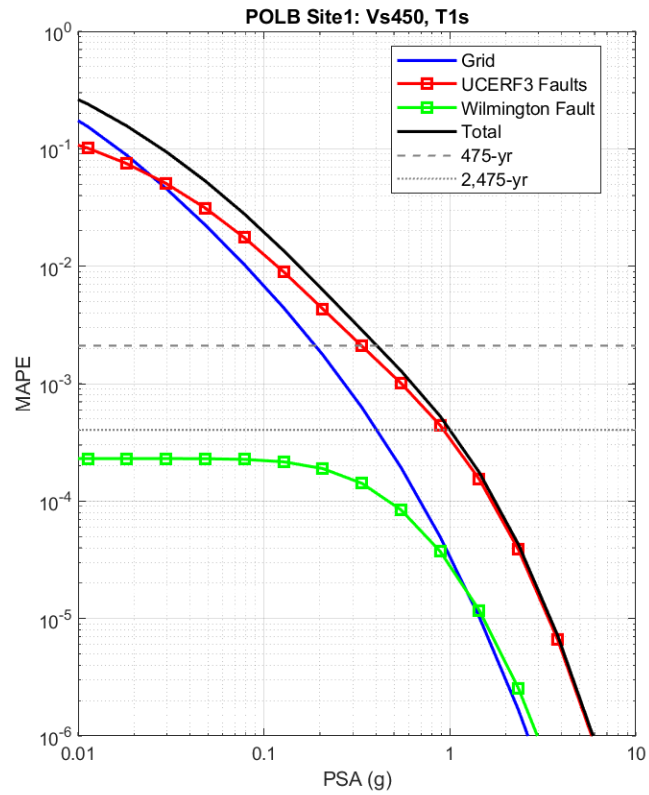


Figure 19. Mean horizontal component hazard curves from the UCERF3 gridded and fault sources, Wilmington fault, and total mean hazard for $T=1.0$ sec for Site 1 for $V_{S30} = 450$ m/sec without directivity. MAPE refers to mean annual probability of exceedance.

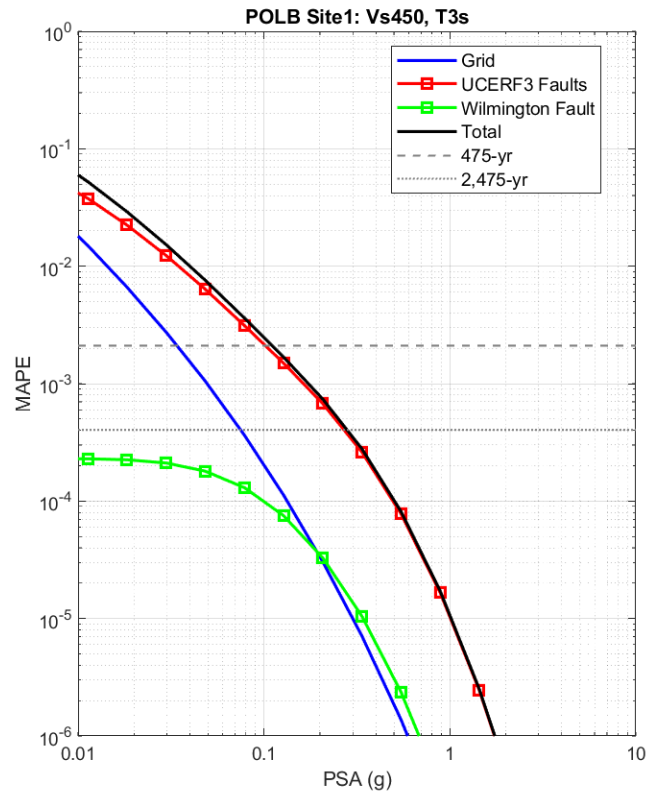


Figure 20. Mean horizontal component hazard curves from the UCERF3 gridded and fault sources, Wilmington fault, and total mean hazard for $T=3.0$ sec for Site 1 for $V_{S30} = 450$ m/sec without directivity. MAPE refers to mean annual probability of exceedance.

To further illustrate the contribution from the parent fault systems from the UCERF3 database and the Wilmington fault, the ranked top 15 contributing parent fault hazard curves at the 2,475-year hazard level are plotted along with the total combined hazard curve from just fault sources including the Wilmington fault. These results are plotted in Figures 21 through 24 for the same previous four spectral periods. Note that given the change in the relative ranking order the line and symbol type for a given parent fault varies from one plot to another. The largest contributing parent fault system to the total fault hazard is the Palos Verdes fault which is an expected result given the close distance to the site and the assigned slip rate for this fault relative to the other faults in the area. The Wilmington fault has a similar contribution as the Compton fault for the intermediate and short periods and a lesser contribution at the longer spectral periods.

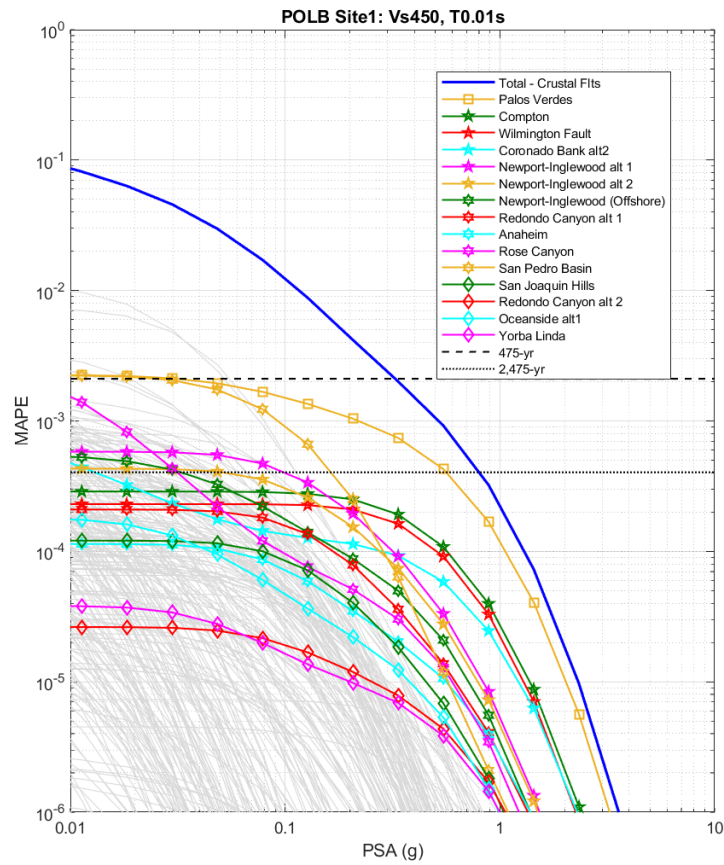


Figure 21. Mean horizontal component hazard curves from the Wilmington and UCERF3 parent fault sources at PGA for Site 1 for $V_{s30} = 450$ m/sec without directivity. The colored individual-fault hazard curves show the top contributing parent faults to the total hazard from crustal faults. MAPE refers to mean annual probability of exceedance.

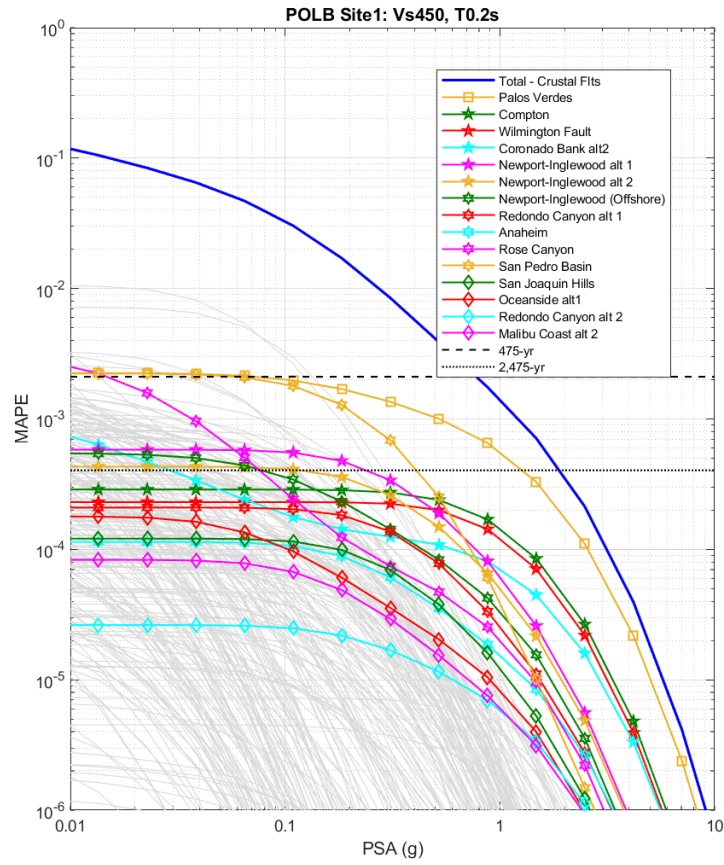


Figure 22. Mean horizontal component hazard curves from the Wilmington and UCERF3 parent fault sources at $T=0.2$ sec for Site 1 for $V_{s30} = 450$ m/sec without directivity. The colored individual-fault hazard curves show the top contributing parent faults to the total hazard from crustal faults. MAPE refers to mean annual probability of exceedance.

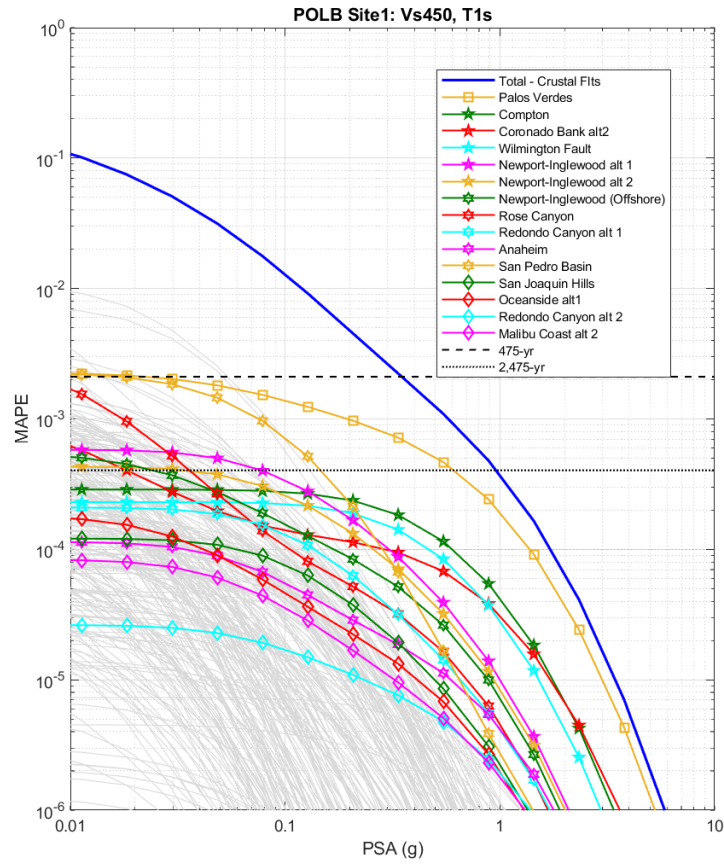


Figure 23. Mean horizontal component hazard curves from the Wilmington and UCERF3 parent fault sources at $T=1.0$ sec for Site 1 for $V_{s30} = 450$ m/sec without directivity. The colored individual-fault hazard curves show the top contributing parent faults to the total hazard from crustal faults. MAPE refers to mean annual probability of exceedance.

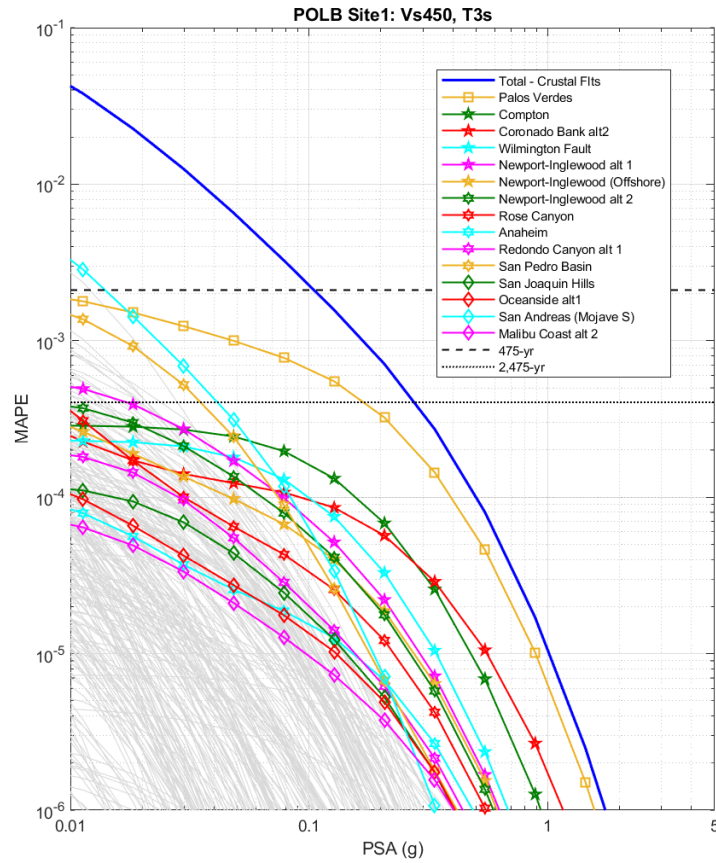


Figure 24. Mean horizontal component hazard curves from the Wilmington and UCERF3 parent fault sources at $T=3.0$ sec for Site 1 for $V_{s30} = 450$ m/sec without directivity. The colored individual-fault hazard curves show the top contributing parent faults to the total hazard from crustal faults. MAPE refers to mean annual probability of exceedance.

Given the hazard curves for the full suite of spectral periods, the computed uniform hazard spectra (UHS) for the selected 72, 475, 975 and 2,475-year return period hazard levels are plotted in Figure 25 for the average horizontal component without the inclusion of the directivity models. These horizontal UHS values for the return period hazard levels at all spectral periods are given in Table 7.

Table 7. Horizontal UHS for Site 1 ($V_{S30} = 450$ m/sec) at the suite of hazard levels without the inclusion of the directivity models.

Period (sec)	72-year Horizontal PSA (g)	475-year Horizontal PSA (g)	975-year Horizontal PSA (g)	2,475-year Horizontal PSA (g)
0.01	0.1535	0.4422	0.6189	0.9013
0.02	0.1545	0.4481	0.6273	0.9130
0.03	0.1647	0.4794	0.6675	0.9660
0.04	0.1823	0.5320	0.7363	1.0571
0.05	0.2019	0.5836	0.8158	1.1673
0.075	0.2580	0.7384	1.0235	1.4843
0.1	0.3077	0.8743	1.1945	1.7081
0.15	0.3600	1.0140	1.4119	1.9959
0.2	0.3680	1.0551	1.4932	2.1461
0.25	0.3560	1.0421	1.4959	2.1961
0.3	0.3364	0.9957	1.4424	2.1445
0.4	0.2867	0.8677	1.2576	1.9044
0.5	0.2474	0.7575	1.1110	1.7169
0.75	0.1725	0.5423	0.8157	1.2935
1	0.1261	0.4047	0.6175	0.9972
1.5	0.0778	0.2543	0.3899	0.6345
2	0.0537	0.1794	0.2753	0.4483
3	0.0319	0.1106	0.1706	0.2795
4	0.0217	0.0778	0.1194	0.1943
5	0.0157	0.0581	0.0889	0.1436
7.5	0.0088	0.0343	0.0510	0.0792
10	0.0055	0.0228	0.0337	0.0514

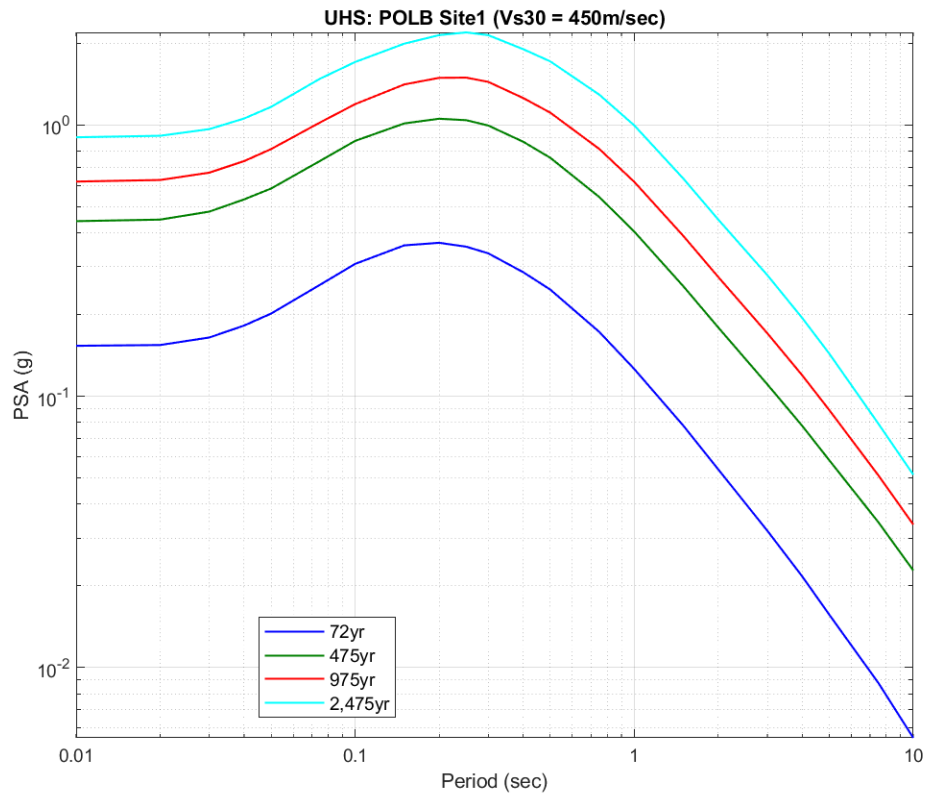


Figure 25. Uniform hazard spectra for Site 1 ($V_{s30} = 450$ m/sec) without the inclusion of the directivity model.

The mean magnitude, distance, and epsilon values for the horizontal component without the directivity models are plotted in Figures 26 to 28 for the selected four hazard levels. These results are plotted as a function of spectral period. In general, the magnitude increases with the increasing return period and spectral periods. For the mean distance values, the distances also decrease as a function of increasing return period but are larger for the longer spectral period given the greater distance to the larger magnitude faults in the region (e.g., San Andreas fault). Finally, the mean epsilon values increase as a function of increasing return periods with the results for the 2,475-year greater than approximately 1 over most of the spectral period range. The mean magnitude, distance, and epsilon values are listed in Tables 9 through 10 for the four hazard levels.

Table 8. Mean magnitude for the four hazard levels for Site 1 ($V_{S30} = 450$ m/sec) without the inclusion of the directivity models.

Period (sec)	72-year Magnitude	475-year Magnitude	975-year Magnitude	2,475-year Magnitude
0.01	6.37	6.62	6.73	6.85
0.02	6.37	6.61	6.73	6.86
0.03	6.35	6.61	6.72	6.84
0.04	6.34	6.59	6.7	6.81
0.05	6.33	6.57	6.68	6.78
0.075	6.29	6.52	6.63	6.74
0.1	6.28	6.52	6.6	6.7
0.15	6.3	6.54	6.66	6.75
0.2	6.34	6.6	6.73	6.83
0.25	6.39	6.66	6.79	6.9
0.3	6.43	6.7	6.83	6.94
0.4	6.52	6.8	6.9	7.01
0.5	6.58	6.85	6.95	7.05
0.75	6.69	6.95	7.03	7.11
1	6.78	7.01	7.08	7.15
1.5	6.91	7.12	7.17	7.22
2	6.99	7.19	7.23	7.26
3	7.11	7.29	7.3	7.31
4	7.19	7.36	7.35	7.35
5	7.23	7.41	7.41	7.39
7.5	7.32	7.52	7.53	7.51
10	7.35	7.58	7.59	7.59

Table 9. Mean distance for the four hazard levels for Site 1 ($V_{S30} = 450$ m/sec) without inclusion of the directivity models.

Period (sec)	72-year Distance (km)	475-year Distance (km)	975-year Distance (km)	2,475-year Distance (km)
0.01	26.92	10.02	6.84	4.74
0.02	26.73	9.88	6.78	4.71
0.03	26.63	9.83	6.99	4.90
0.04	26.36	9.50	7.17	5.16
0.05	25.96	9.96	7.26	5.45
0.075	26.17	10.87	7.92	5.70
0.1	25.76	10.50	8.30	6.17
0.15	26.16	10.93	7.81	6.08
0.2	27.07	11.16	7.50	5.77
0.25	28.14	11.33	7.43	5.54
0.3	29.35	11.62	7.58	5.49
0.4	32.26	12.01	8.47	5.53
0.5	35.26	13.84	9.07	5.53
0.75	40.13	15.15	9.68	5.74
1	42.21	17.05	10.14	5.71
1.5	48.46	20.38	12.18	6.68
2	52.82	22.52	13.95	7.66
3	58.50	25.70	15.98	8.60
4	62.37	27.94	17.89	9.81
5	64.85	31.79	21.13	12.31
7.5	73.05	42.33	33.62	24.78
10	78.95	49.03	41.63	34.08

Table 10. Mean epsilon for the four hazard levels for Site 1 ($V_{S30} = 450$ m/sec) without inclusion of the directivity models.

Period (sec)	72-year Epsilon	475-year Epsilon	975-year Epsilon	2,475-year Epsilon
0.01	0.08	0.48	0.73	1.14
0.02	0.08	0.48	0.73	1.14
0.03	0.10	0.51	0.76	1.15
0.04	0.12	0.54	0.79	1.16
0.05	0.16	0.57	0.83	1.18
0.075	0.21	0.67	0.90	1.27
0.1	0.24	0.71	0.94	1.28
0.15	0.21	0.67	0.91	1.23
0.2	0.18	0.60	0.83	1.17
0.25	0.17	0.54	0.77	1.10
0.3	0.20	0.52	0.74	1.07
0.4	0.21	0.48	0.69	1.03
0.5	0.22	0.47	0.66	1.01
0.75	0.26	0.45	0.62	0.97
1	0.25	0.41	0.57	0.94
1.5	0.23	0.40	0.56	0.92
2	0.18	0.39	0.56	0.91
3	0.09	0.36	0.54	0.89
4	-0.01	0.35	0.55	0.90
5	-0.07	0.37	0.57	0.92
7.5	-0.19	0.45	0.72	1.08
10	-0.30	0.44	0.75	1.13

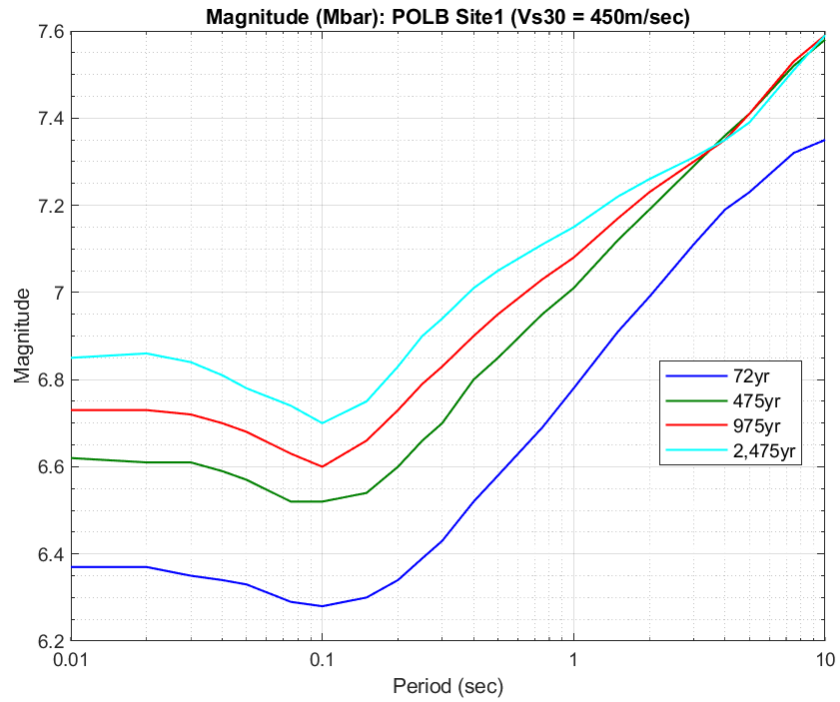


Figure 26. Horizontal mean magnitude for Site 1 ($V_{s30} = 450$ m/sec) without the inclusion of the directivity models.

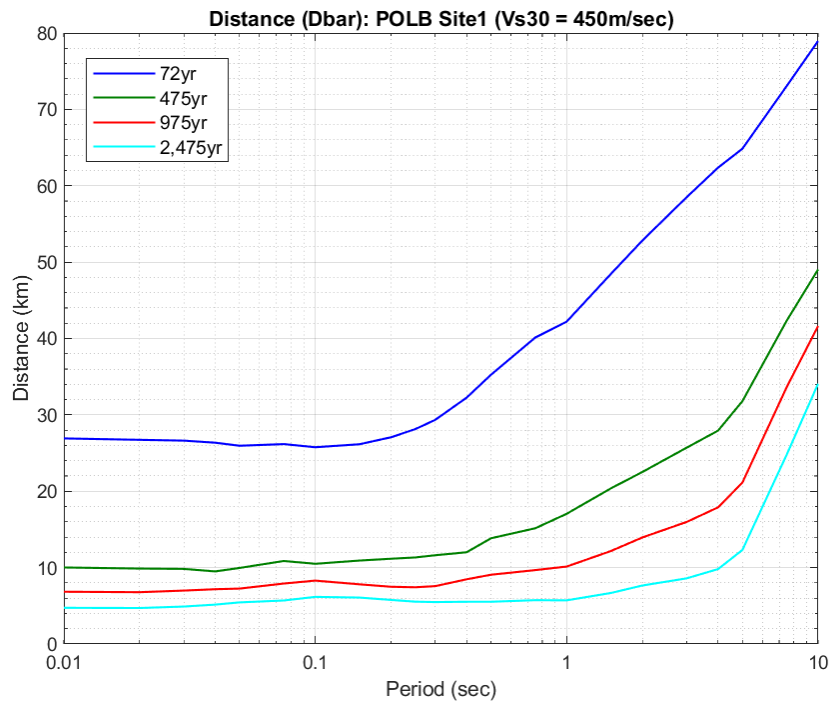


Figure 27. Horizontal mean distance for Site 1 ($V_{s30} = 450$ m/sec) without the inclusion of the directivity models.

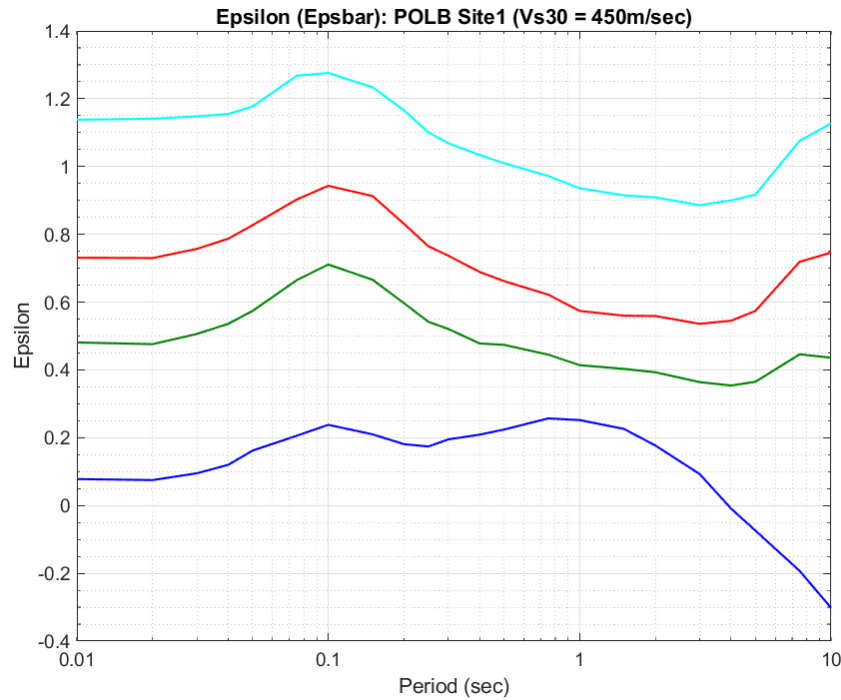


Figure 28. Horizontal mean epsilon for Site 1 ($V_{s30} = 450$ m/sec) without the inclusion of the directivity models.

The binned magnitude and distance contributions to the 72-year hazard level are shown in Figures 29 to 32 for Site 1 ($V_{s30} = 450$ m/sec) for PGA and spectral periods of 0.2, 1.0, and 3.0 sec. Similar plots are shown in Figures 33 to 36 for the 475-year hazard level, Figures 37 to 40 for the 975-year hazard level, and Figures 41 to 44 for the 2,475-year hazard level.

At the shortest return period level of 72-year, the hazard is being contributed to from small to moderate magnitude events over a broad distance of less than about 100 km. At the longer spectral periods, a relative increase in the contribution to the total hazard is observed for the larger magnitude (i.e., greater than 7.0) in the distance bin of 50 – 100 km. This corresponds to the contribution from the San Andreas and San Jacinto faults with their relatively higher slip rates. At the longer return period hazard levels, the relative increased contribution of the local faults to the total hazard is observed in the deaggregation plots with the majority of the contribution from sources with distance less than about 50 km. Based on this increased contribution from these local faults, the relative contribution from the San Andreas fault is decreased even at the longer spectral periods.

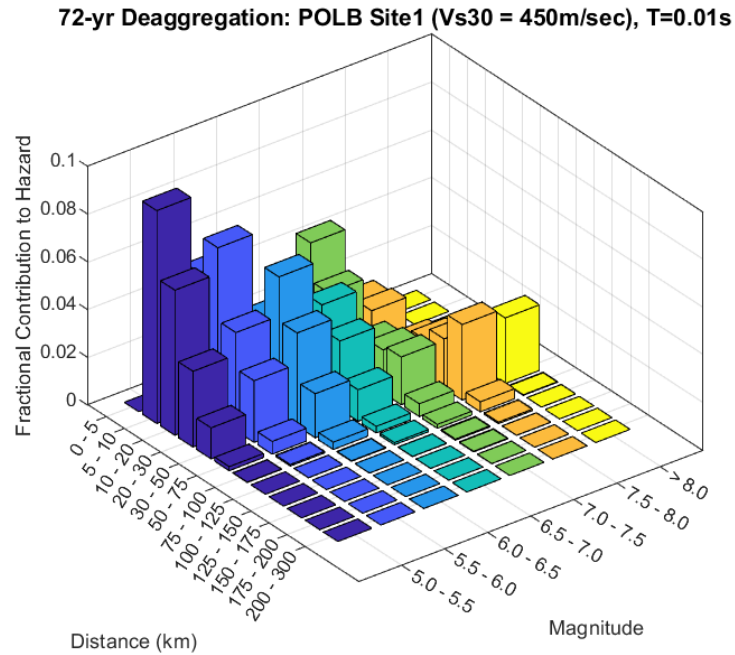


Figure 29. Magnitude-distance contribution for the 72-year hazard level for PGA for Site 1 ($V_{s30} = 450\text{ m/sec}$).

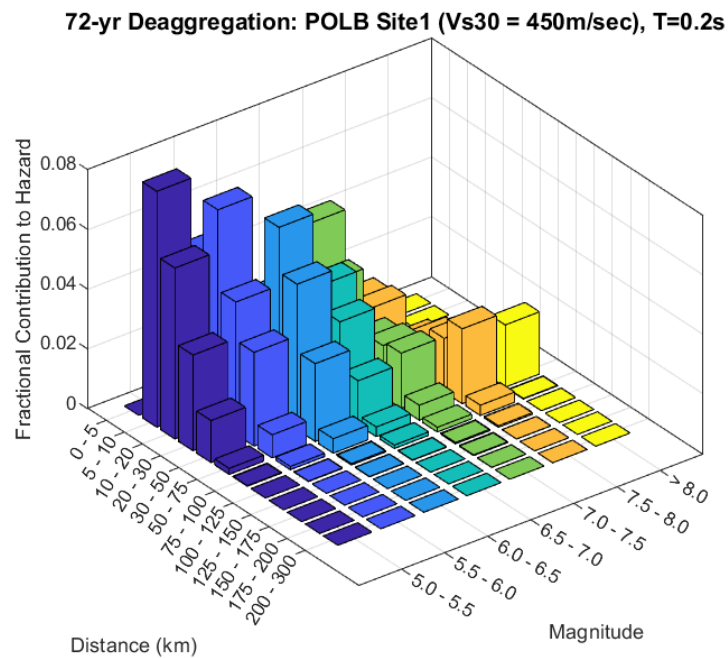


Figure 30. Magnitude-distance contribution for the 72-year hazard level for $T = 0.2\text{ sec}$ for Site 1 ($V_{s30} = 450\text{ m/sec}$).

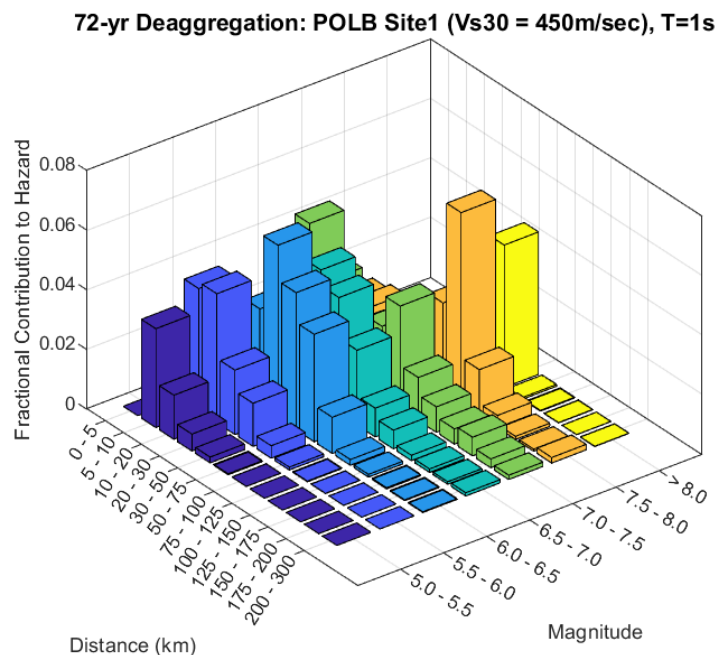


Figure 31. Magnitude-distance contribution for the 72-year hazard level for T = 1.0 sec for Site 1 ($V_{s30} = 450$ m/sec).

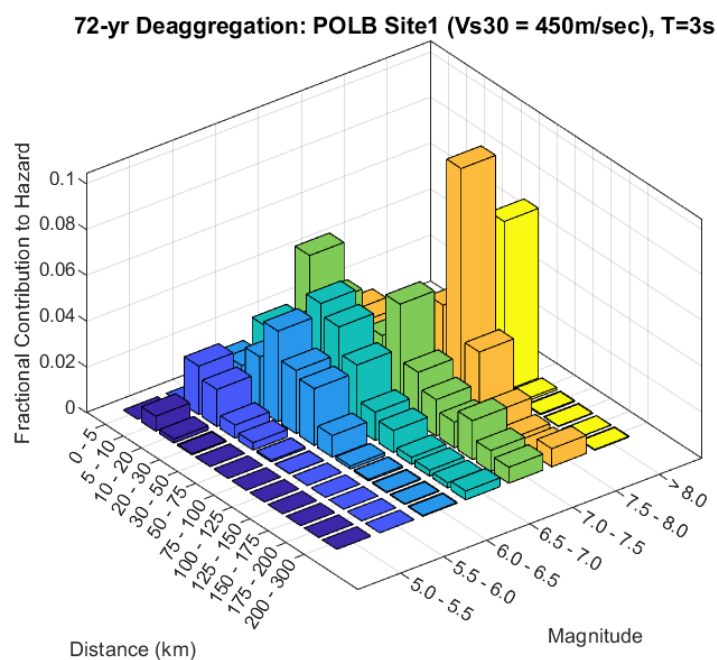


Figure 32. Magnitude-distance contribution for the 72-year hazard level for T = 3.0 sec for Site 1 ($V_{s30} = 450$ m/sec).

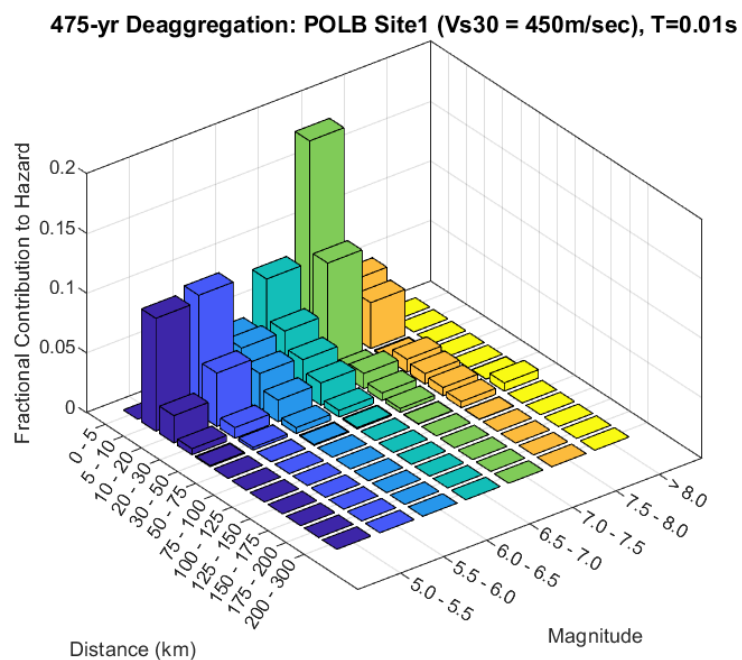


Figure 33. Magnitude-distance contribution for the 475-year hazard level for PGA for Site 1 ($V_{s30} = 450\text{ m/sec}$).

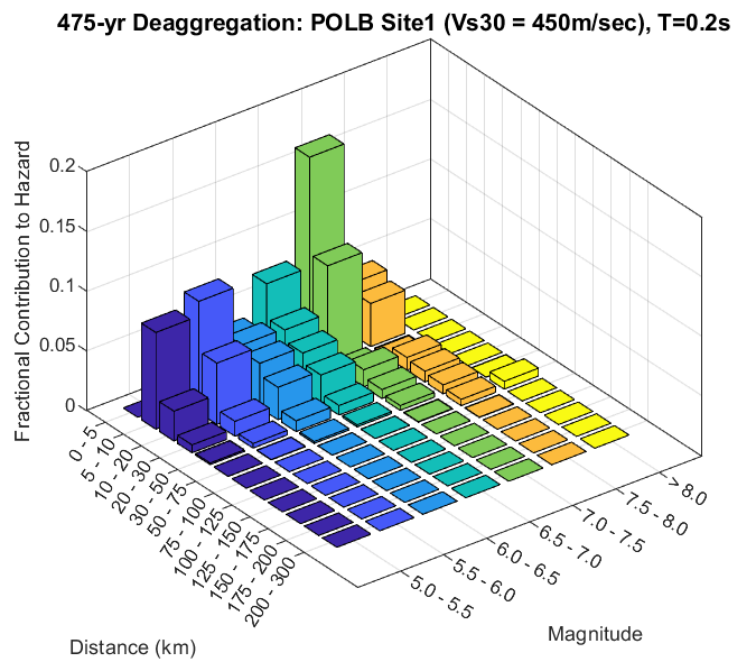


Figure 34. Magnitude-distance contribution for the 475-year hazard level for $T = 0.2\text{ sec}$ for Site 1 ($V_{s30} = 450\text{ m/sec}$).

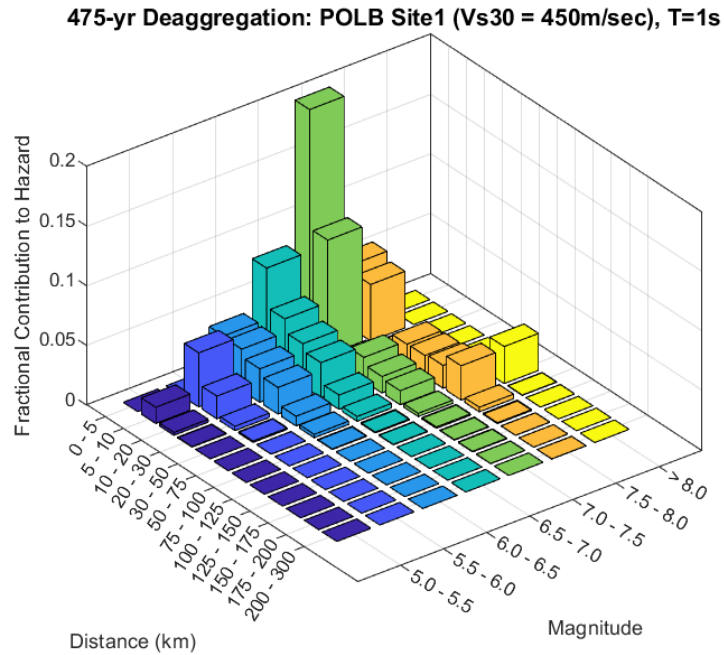


Figure 35. Magnitude-distance contribution for the 475-year hazard level for $T = 1.0$ sec for Site 1 ($V_{s30} = 450$ m/sec).

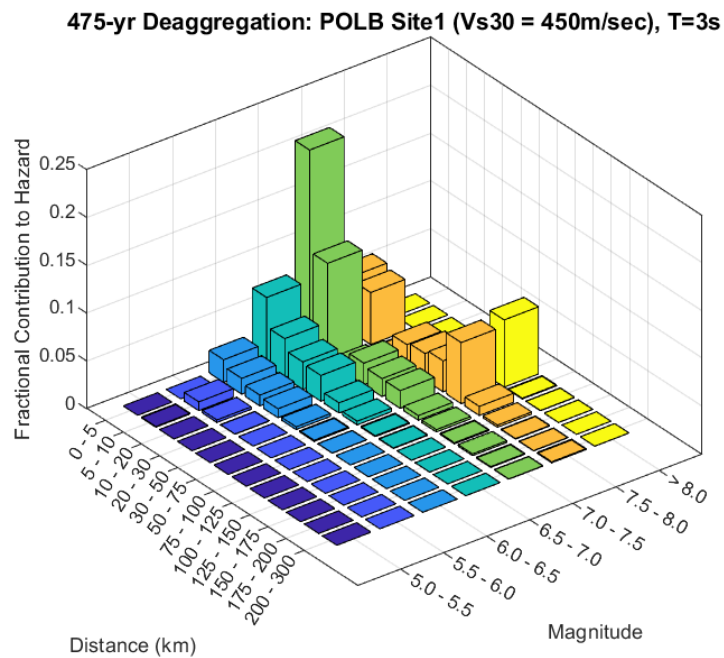


Figure 36. Magnitude-distance contribution for the 475-year hazard level for $T = 3.0$ sec for Site 1 ($V_{s30} = 450$ m/sec).

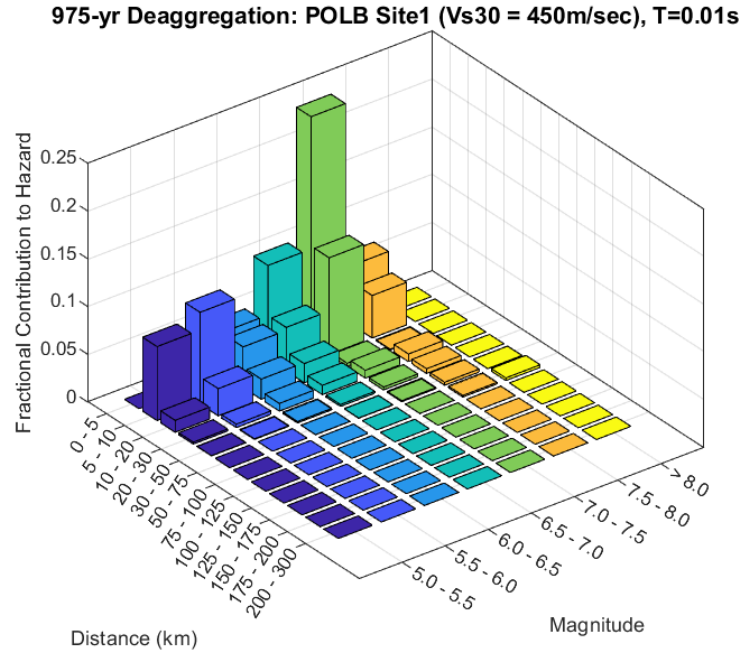


Figure 37. Magnitude-distance contribution for the 975-year hazard level for PGA for Site 1 ($V_{s30} = 450$ m/sec).

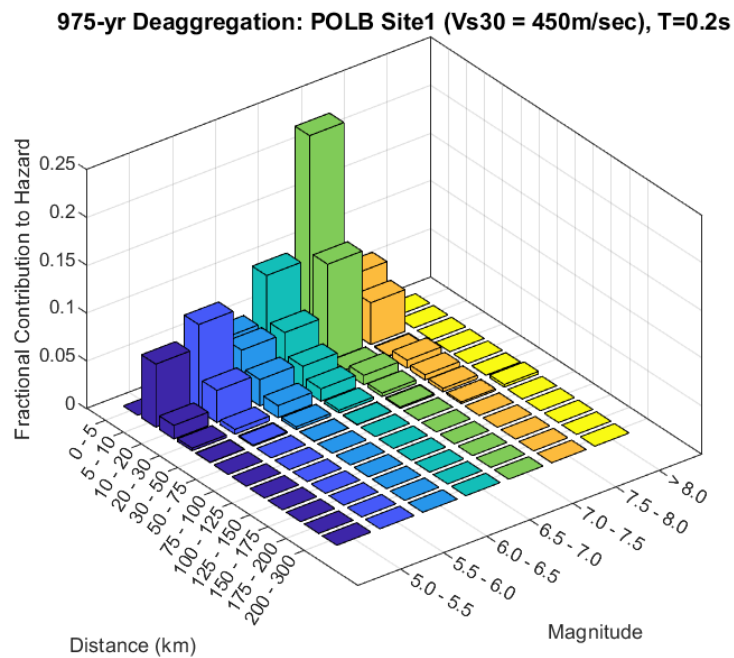


Figure 38. Magnitude-distance contribution for the 975-year hazard level for $T = 0.2$ sec for Site 1 ($V_{s30} = 450$ m/sec).

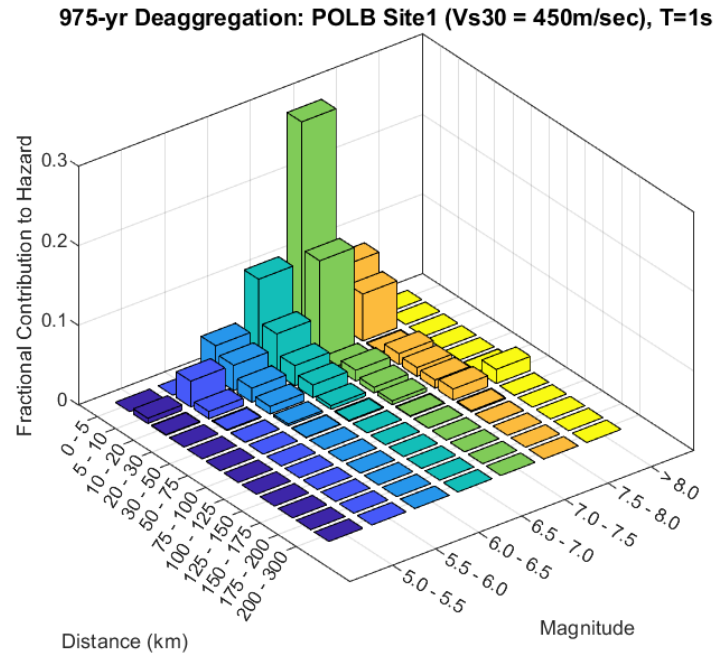


Figure 39. Magnitude-distance contribution for the 975-year hazard level for T = 1.0 sec for Site 1 ($V_{s30} = 450$ m/sec).

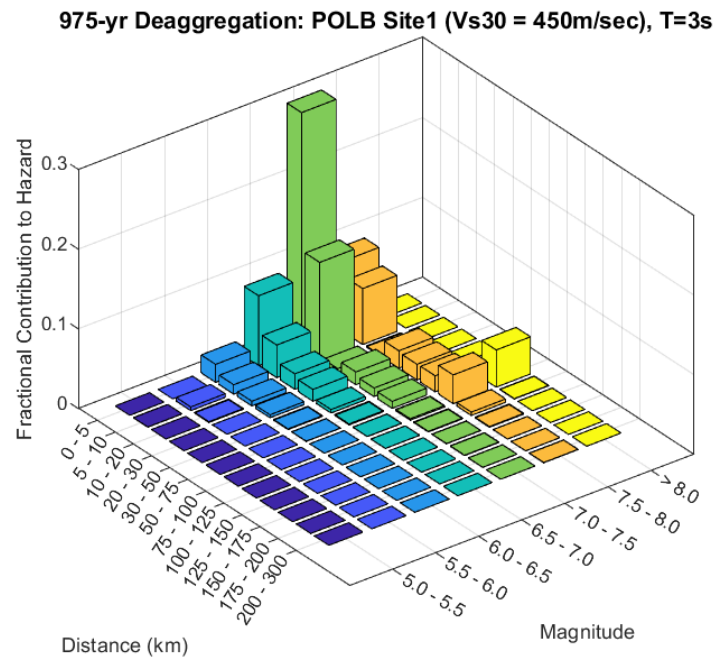


Figure 40. Magnitude-distance contribution for the 975-year hazard level for T = 3.0 sec for Site 1 ($V_{s30} = 450$ m/sec).

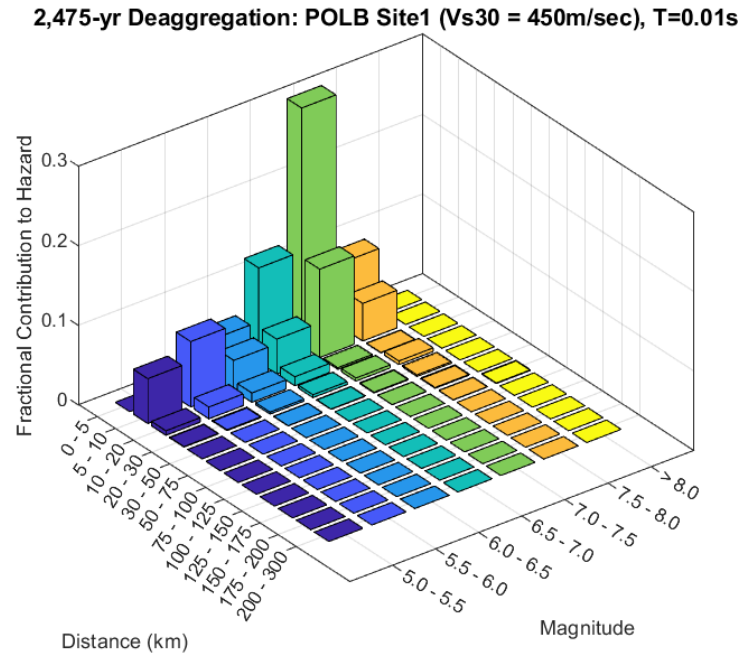


Figure 41. Magnitude-distance contribution for the 2,475-year hazard level for PGA for Site 1 ($V_{s30} = 450$ m/sec).

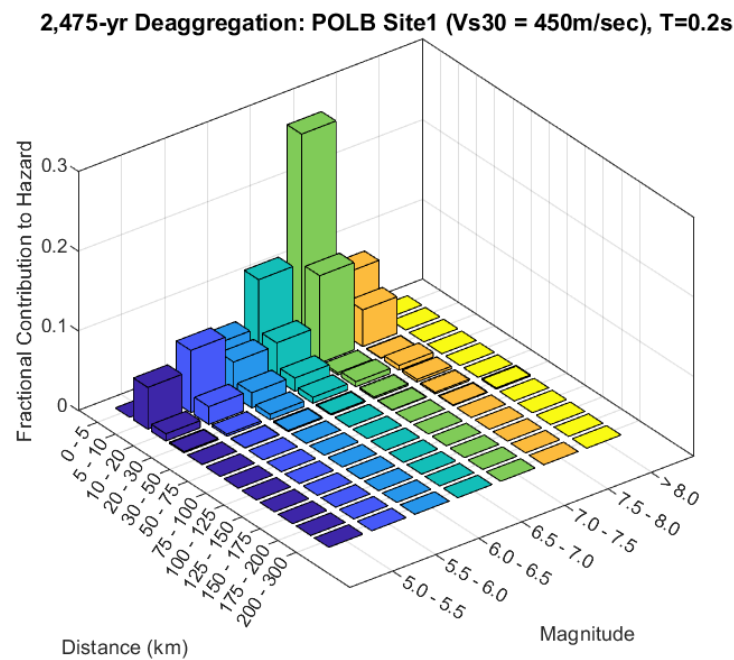


Figure 42. Magnitude-distance contribution for the 2,475-year hazard level for $T = 0.2$ sec for Site 1 ($V_{s30} = 450$ m/sec).

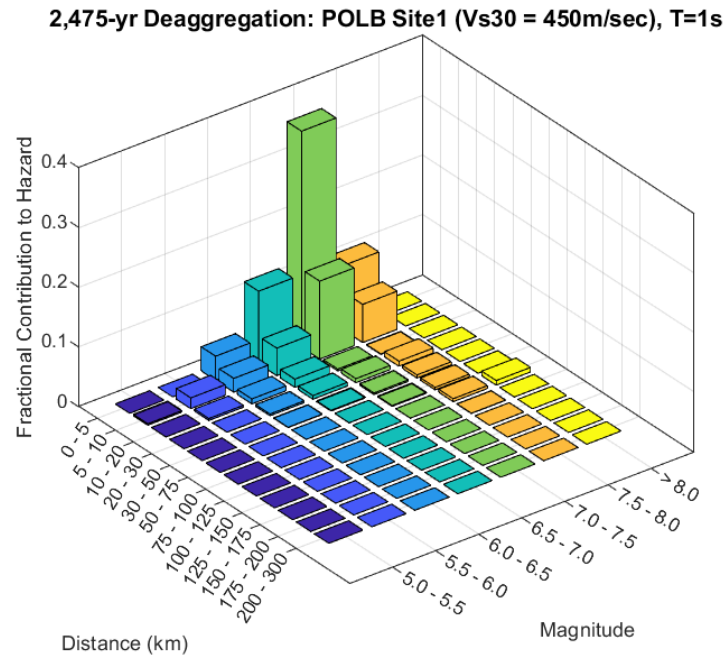


Figure 43. Magnitude-distance contribution for the 2,475-year hazard level for T = 1.0 sec for Site 1 ($V_{s30} = 450$ m/sec).

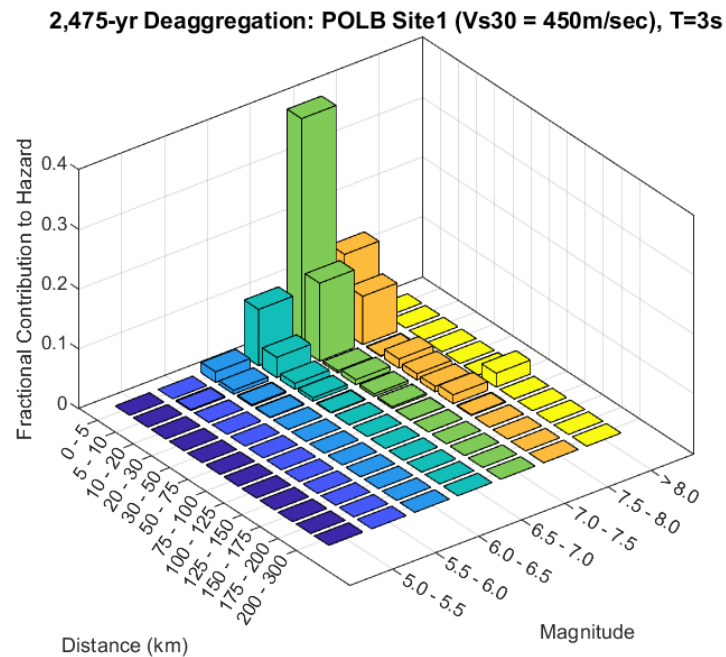


Figure 44. Magnitude-distance contribution for the 2,475-year hazard level for T = 3.0 sec for Site 1 ($V_{s30} = 450$ m/sec).

The hazard results obtained from this study are compared to results from the NSHM 2018 (NSHM18) and the NSHM 2023 (NSHM23) for Site 1 with V_{S30} of 450 m/sec. The NSHM results were queried from <https://earthquake.usgs.gov/nshmp/hazard/dynamic> for the coordinates of Site 1 and a V_{S30} of 450 m/sec. Note that NSHM website does not allow for inputs of Z_1 and $Z_{2.5}$ values. Figure 45 shows a comparison of the UHS from this study to the NSHM UHS curves for return periods of 100, 475, 975, and 2,475 years. These comparisons are based on the horizontal component without the inclusion of directivity. Also for this comparison the results from this study are computed for the additional hazard level of 100 years. In this figure, the results from this study are referred to as “Haz45” and are shown with solid lines while the dashed lines show the NSHM18 results and the dashed with symbols lines show the NSHM23 results. The ratio of the UHS curves from this study to those from NSHM18 and NSHM23 are shown in Figure 46.

As shown in Figures 45 and 46, the NSHM23 UHS are larger than those obtained from the NSHM18 at all spectral periods and return periods. This difference is on the order of 10%. At short periods, the ground motions from this study are comparable to those obtained from the NSHMs and fall between the NSHM18 and NSHM23 results. The ratio of the UHS from this study to those from the NSHMs is within 12% at periods less than 1 sec. At the longer spectral periods, a significant difference between the results from this study and the NSHMs can be observed with the ground motions from this study lower than those from the NSHMs by 20% or more. This difference at long periods is due to the use of a large Z_1 value of about 0.76 km in the NSHMs (USGS personal communication) for this site compared to 0.3 km in this study. The use of this larger Z_1 value would lead to a significant increase in the long period ground motions from the basin amplification aspect of the GMMs given a large relative Z_1 value between the default value and the assigned value. As part of this study and the evaluation of the basin depth parameters presented in Section 3.1, the use of Z_1 of 0.76 km is not justified for this site based on the community velocity models in the region.

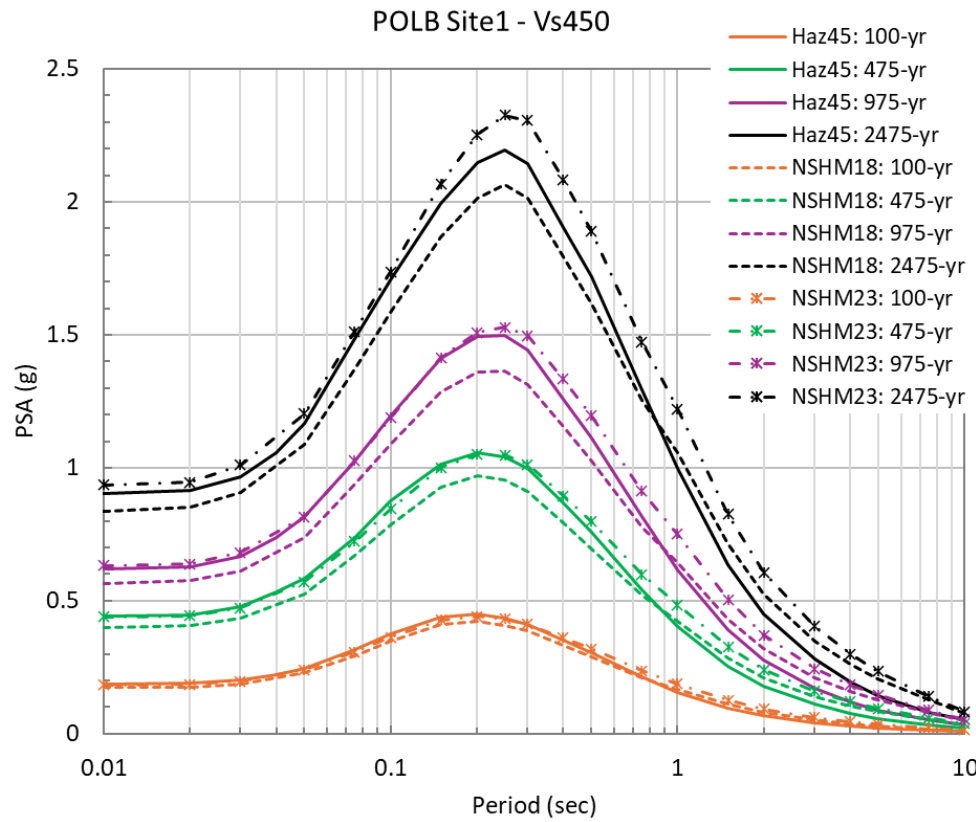


Figure 45. Comparison of the UHS from this study to the NSHMs UHS for Site 1 ($V_{s30} = 450$ m/sec).

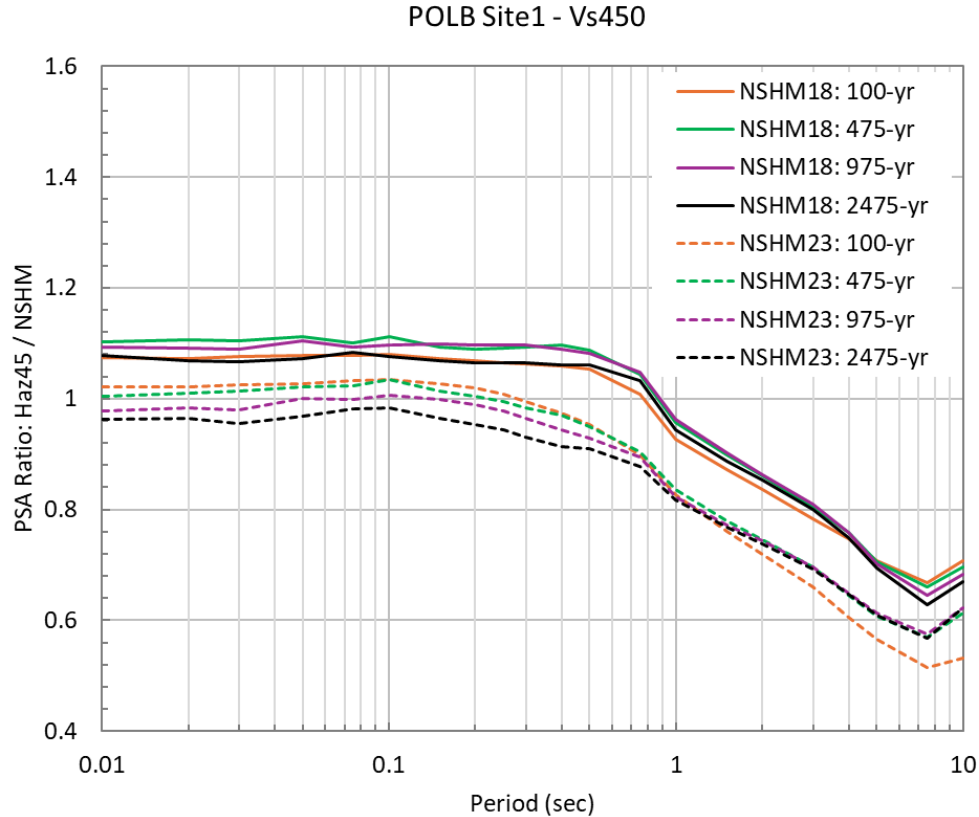


Figure 46. Ratio of the UHS from this study relative to the NSHMs UHS for Site 1 ($V_{s30} = 450$ m/sec).

4.2.2 Site 1 Results with Directivity, $V_{s30} = 450$ m/sec

The results for Site 1 with $V_{s30} = 450$ m/sec with the inclusion of the directivity models are presented in this section. Note that the adjustments based on the directivity models only impact the longer spectral period ground motions (i.e., periods equal to and greater than 0.5 sec) and the results presented earlier for the shorter periods are unaffected by the directivity models. The mean total hazard curves for spectral periods of 1.0, 3.0, 5.0 and 10.0 seconds are plotted in Figures 47 through 50. In each plot, the individual hazard curves for each directivity model are plotted along with the weighted mean (dashed light blue line) using the assigned weights for the suite of directivity models. For comparison the mean hazard curve without directivity is also plotted (heavy black line).

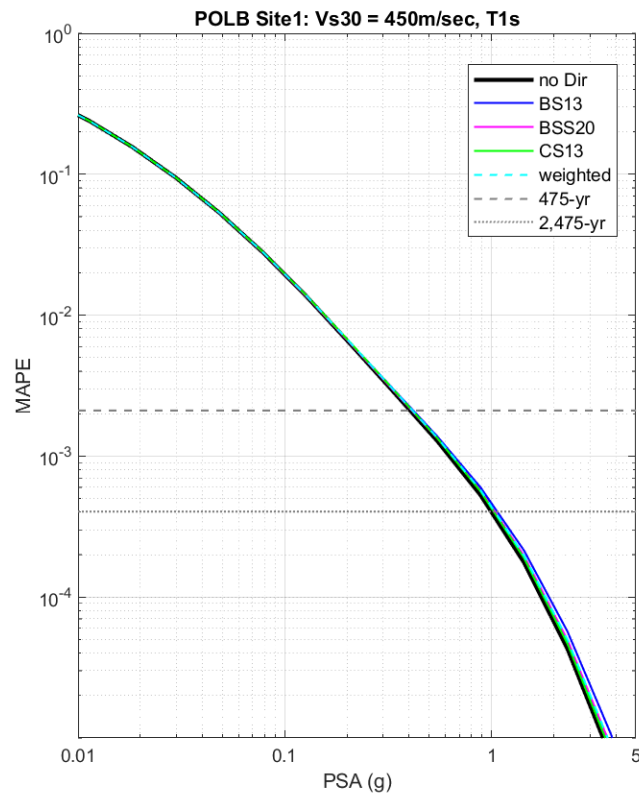


Figure 47. Total mean hazard curves without directivity (heavy black line), individual directivity models and weighted directivity results (dashed blue line) for Site 1 ($V_{s30} = 450$ m/sec) for $T=1.0$ sec spectral period. MAPE refers to mean annual probability of exceedance.

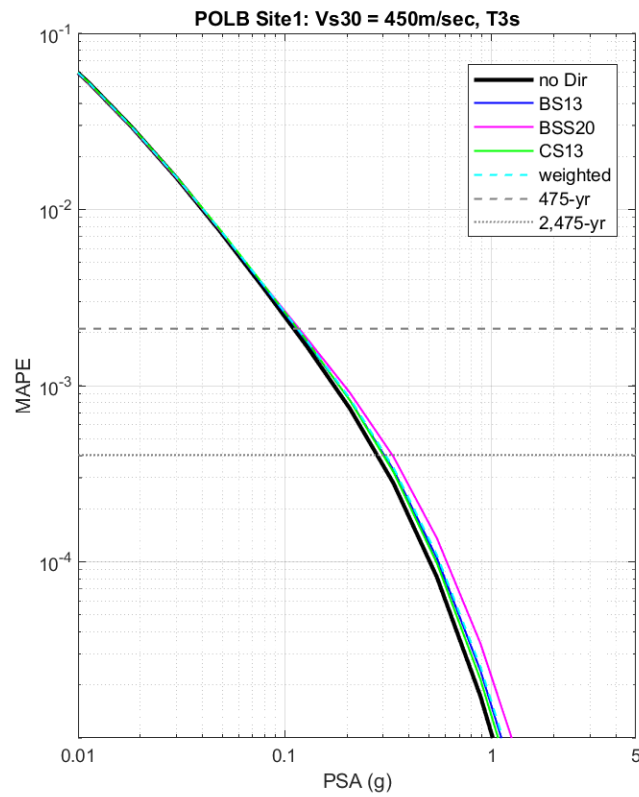


Figure 48. Total mean hazard curves without directivity (heavy black line), individual directivity models and weighted directivity results (dashed blue line) for Site 1 ($V_{s30} = 450$ m/sec) for $T=3.0$ sec spectral period. MAPE refers to mean annual probability of exceedance.

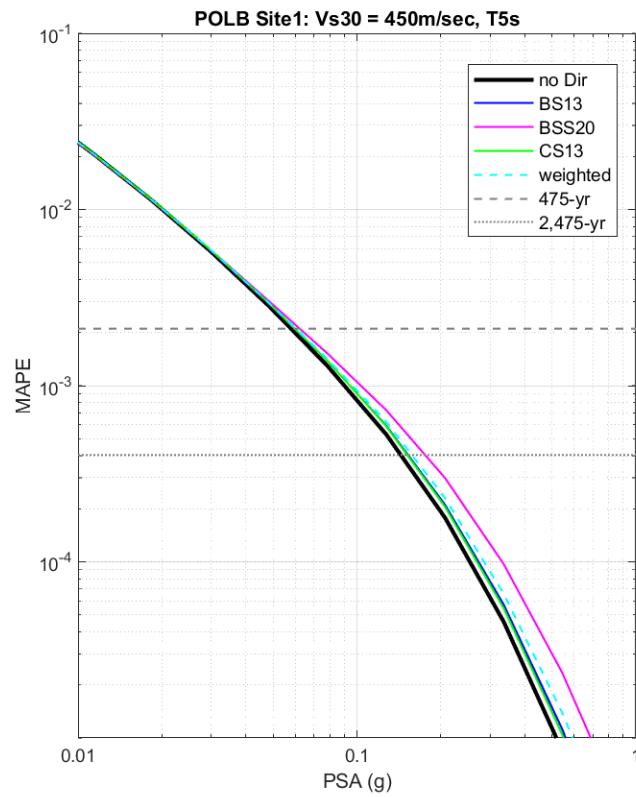


Figure 49. Total mean hazard curves without directivity (heavy black line), individual directivity models and weighted directivity results (dashed blue line) for Site 1 ($V_{S30} = 450$ m/sec) for $T=5.0$ sec spectral period. MAPE refers to mean annual probability of exceedance.

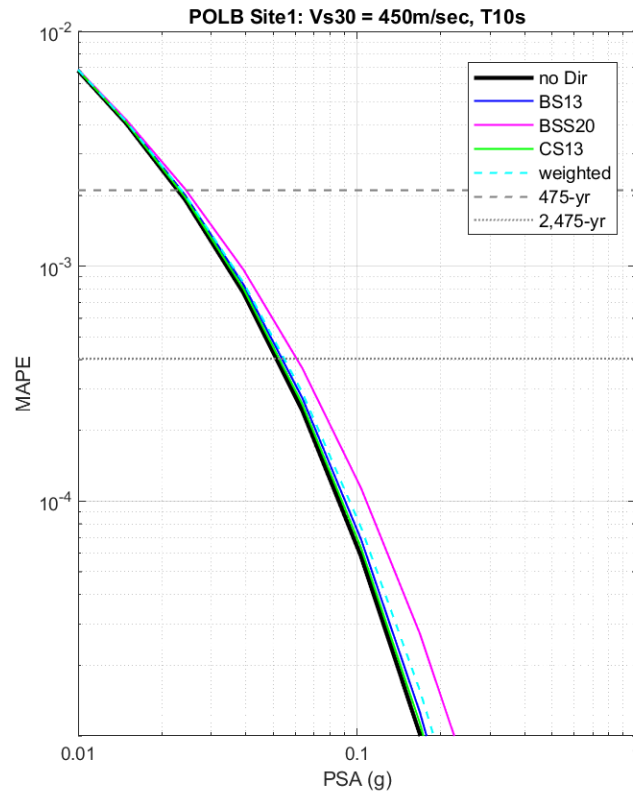


Figure 50. Total mean hazard curves without directivity (heavy black line), individual directivity models and weighted directivity results (dashed blue line) for Site 1 ($V_{s30} = 450$ m/sec) for $T=10.0$ sec spectral period. MAPE refers to mean annual probability of exceedance.

All of the directivity models show an increase in the hazard with the BSS20 model yielding the largest increase. To observe the impact on the ground motions from these directivity models, spectral ratios of the UHS ground motions are computed and plotted in Figure 51 through 54 for the selected four hazard levels. At the 72-year hazard level there is minimal impact from the directivity models. For the longer return period levels, the results from the directivity models increase, especially for the longer spectral periods, beyond the period range of interest for this project. The UHS including the weighted combination of the directivity models for the four return period levels are listed in Table 11. The comparison of the UHS both with and without the directivity models are plotted in Figures 55 through 58 for the selected four hazard levels. Overall, the increase in the long-period ground motion due to directivity effects is observed to be less than or equal to 10% for the weighted directivity models. Similar deaggregation results are observed for the directivity cases and are not presented in the report.

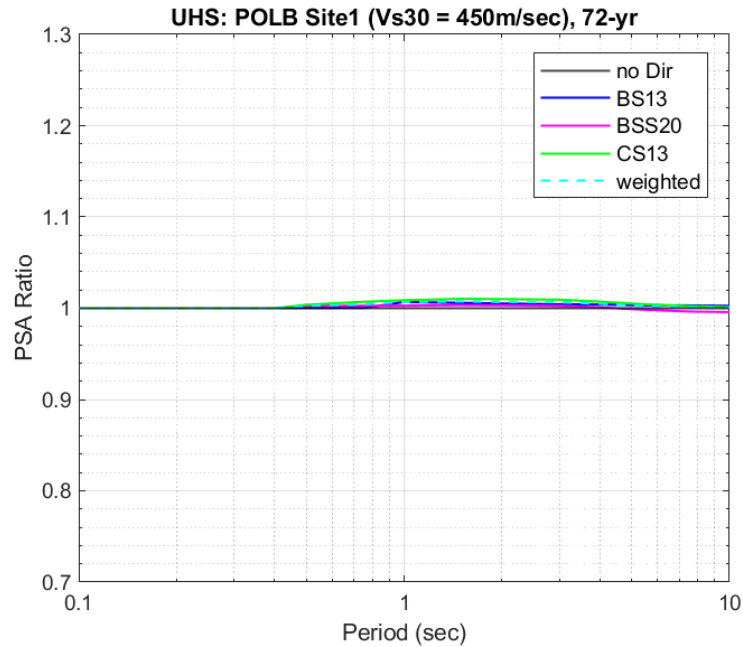


Figure 51. UHS spectral ratio for Site 1 ($V_{s30} = 450\text{ m/sec}$) for the 72-year return period hazard level for the individual and weighted combination directivity models.

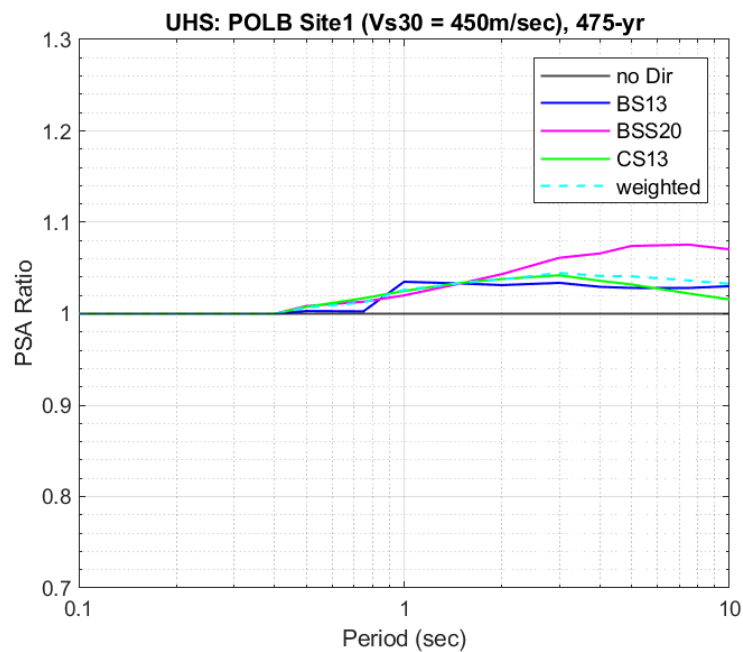


Figure 52. UHS spectral ratio for Site 1 ($V_{s30} = 450\text{ m/sec}$) for the 475-year return period hazard level for the individual and weighted combination directivity models.

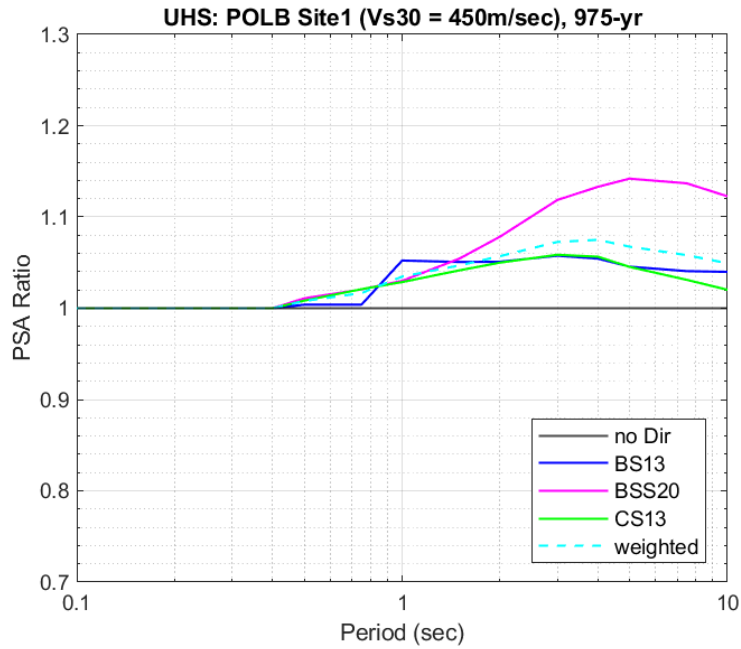


Figure 53. UHS spectral ratio for Site 1 ($V_{s30} = 450$ m/sec) for the 975-year return period hazard level for the individual and weighted combination directivity models.

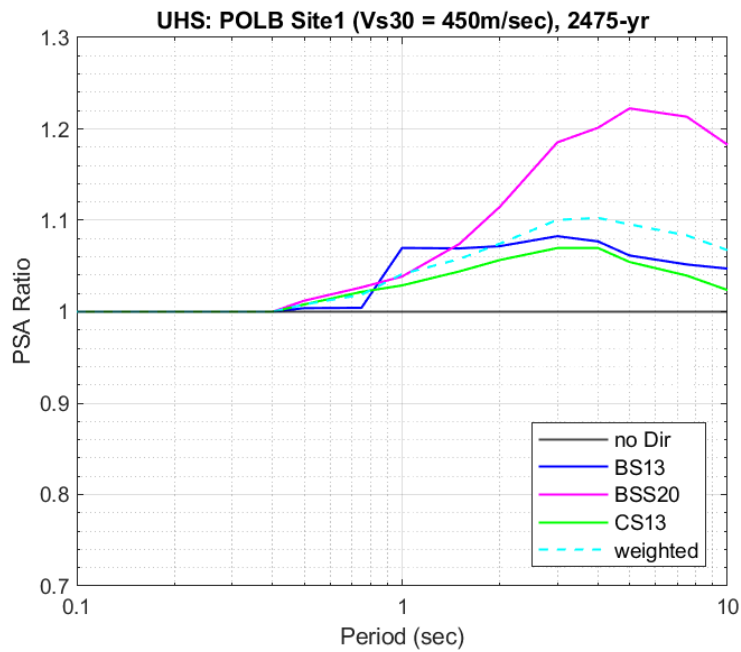


Figure 54. UHS spectral ratio for Site 1 ($V_{s30} = 450$ m/sec) for the 2,475-year return period hazard level for the individual and weighted combination directivity models.

Table 11. Horizontal UHS for Site 1 ($V_{S30} = 450$ m/sec) at the four hazard levels with the inclusion of the combined weighted directivity models.

Period (sec)	72-year Horizontal PSA (g)	475-year Horizontal PSA (g)	975-year Horizontal PSA (g)	2,475-year Horizontal PSA (g)
0.01	0.1535	0.4422	0.6189	0.9013
0.02	0.1545	0.4481	0.6273	0.9130
0.03	0.1647	0.4794	0.6675	0.9660
0.04	0.1823	0.5320	0.7363	1.0571
0.05	0.2019	0.5836	0.8158	1.1673
0.075	0.2580	0.7384	1.0235	1.4843
0.1	0.3077	0.8743	1.1945	1.7081
0.15	0.3600	1.0140	1.4119	1.9959
0.2	0.3680	1.0551	1.4932	2.1461
0.25	0.3560	1.0421	1.4959	2.1961
0.3	0.3364	0.9957	1.4424	2.1445
0.4	0.2867	0.8677	1.2576	1.9044
0.5	0.2480	0.7625	1.1197	1.7305
0.75	0.1733	0.5490	0.8292	1.3175
1	0.1269	0.4153	0.6389	1.0383
1.5	0.0784	0.2628	0.4082	0.6711
2	0.0541	0.1861	0.2910	0.4817
3	0.0321	0.1155	0.1830	0.3076
4	0.0218	0.0810	0.1284	0.2143
5	0.0157	0.0604	0.0949	0.1573
7.5	0.0088	0.0355	0.0540	0.0858
10	0.0055	0.0235	0.0353	0.0548

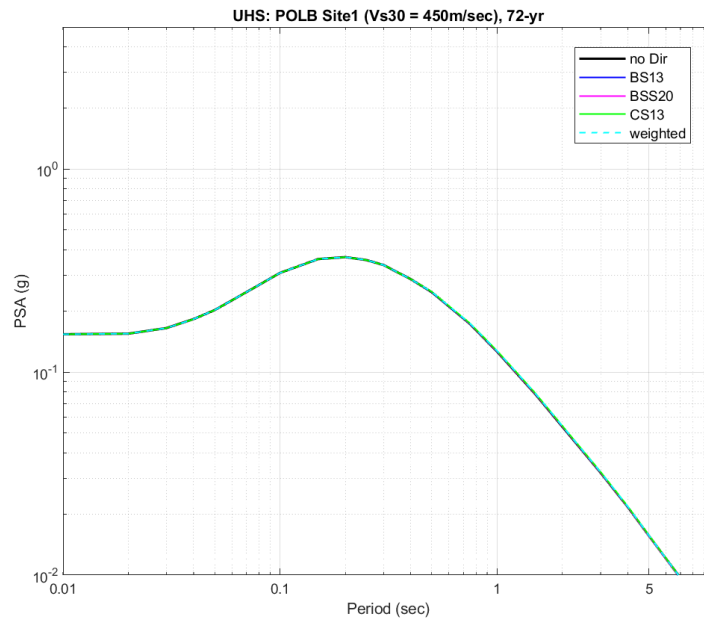


Figure 55. Uniform hazard spectra for Site 1 ($V_{s30} = 450$ m/sec) without directivity (black line) and with the individual and combined weighted (dashed blue line) directivity models for the 72-year return period.

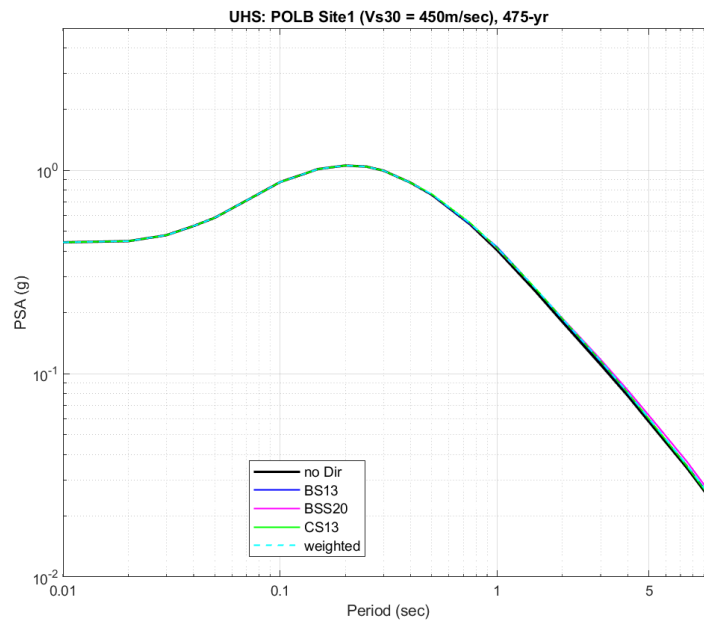


Figure 56. Uniform hazard spectra for Site 1 ($V_{s30} = 450$ m/sec) without directivity (black line) and with the individual and combined weighted (dashed blue line) directivity models for the 475-year return period.

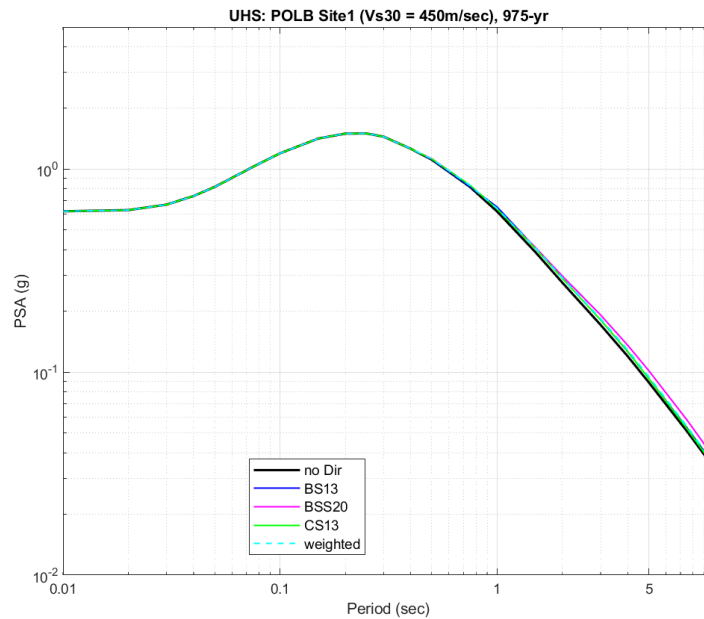


Figure 57. Uniform hazard spectra for Site 1 ($V_{s30} = 450$ m/sec) without directivity (black line) and with the individual and combined weighted (dashed blue line) directivity models for the 975-year return period.

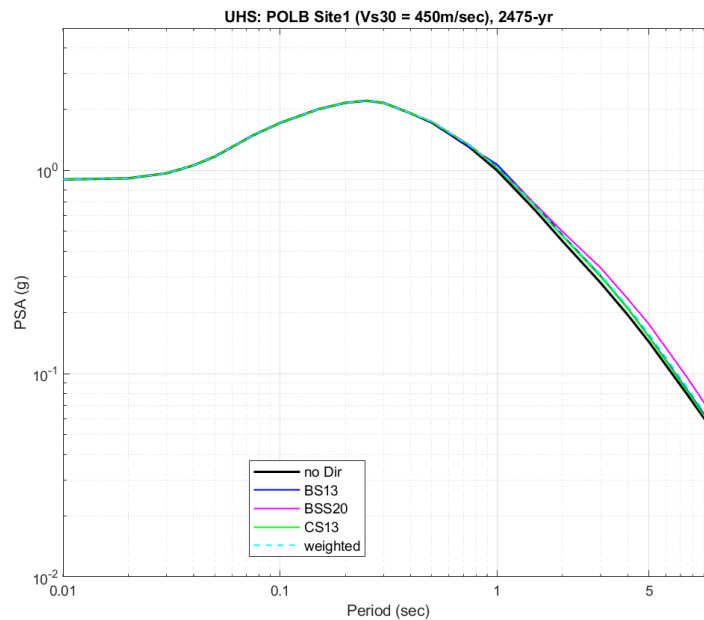


Figure 58. Uniform hazard spectra for Site 1 ($V_{s30} = 450$ m/sec) without directivity (black line) and with the individual and combined weighted (dashed blue line) directivity models for the 2,475-year return period.

Only the Bayless and Somerville (2013) directivity model is defined for the fault normal and fault parallel components of motions including directivity. The other directivity models are defined for the average horizontal component including directivity. Thus, ground motions are computed based on the application of only the Bayless and Somerville (2013) directivity model for the three cases of average horizontal, fault normal and fault parallel components. The resulting UHS for the selected four return period hazard levels are plotted in Figure 59 through 62 and listed in Table 12 through Table 14. The spectral ratio results are plotted in Figure 63 through 66 for the selected return periods. These results show a small impact from the application of the BS13 directivity model for the 72-yr hazard level. The impact, however, increases with increasing return period hazard level and as well spectral period. For the longer return period hazard levels and longer spectral periods, the fault normal results are increased up to about 17% relative to the average horizontal component with directivity. For the fault parallel component, the ground motions are observed to approach a reduction of approximately 10% relative to the average horizontal component.

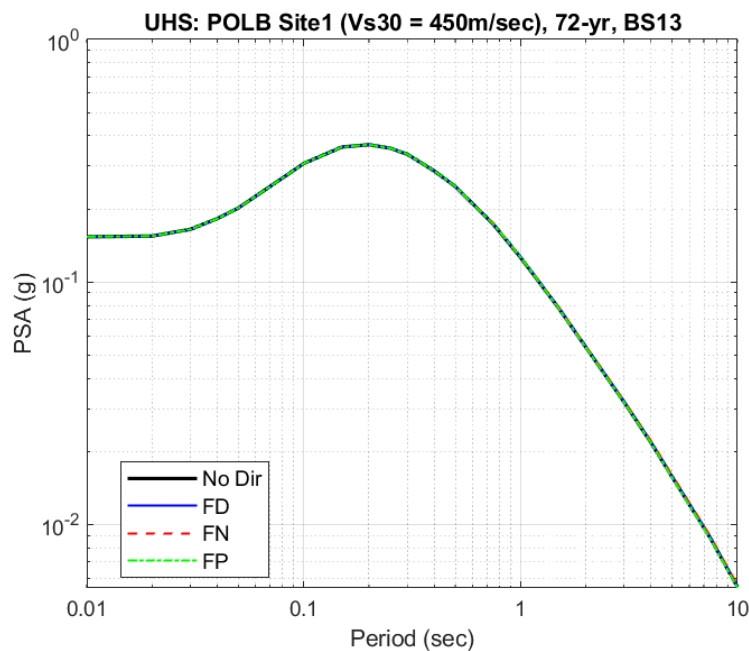


Figure 59. Uniform hazard spectra for Site 1 ($V_{s30} = 450$ m/sec) without directivity (black line) and with the BS13 directivity model for average horizontal (FD), fault normal (FN) and fault parallel (FP) components for the 72-year return period.

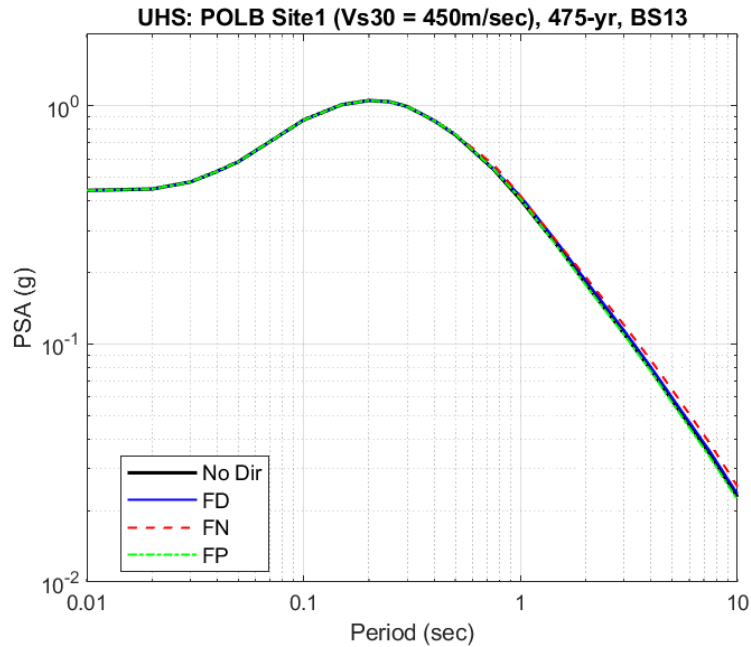


Figure 60. Uniform hazard spectra for Site 1 ($V_{s30} = 450$ m/sec) without directivity (black line) and with the BS13 directivity model for average horizontal (FD), fault normal (FN) and fault parallel (FP) components for the 475-year return period.

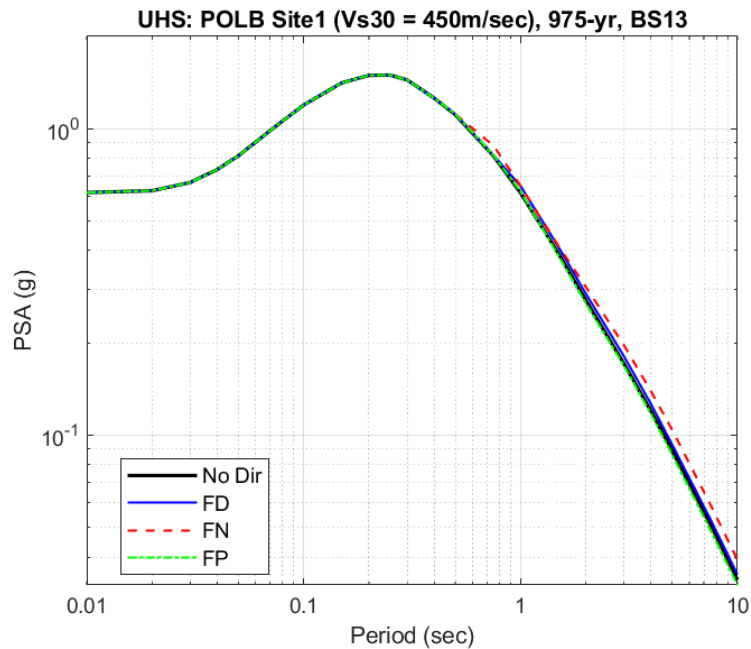


Figure 61. Uniform hazard spectra for Site 1 ($V_{s30} = 450$ m/sec) without directivity (black line) and with the BS13 directivity model for average horizontal (FD), fault normal (FN) and fault parallel (FP) components for the 975-year return period.

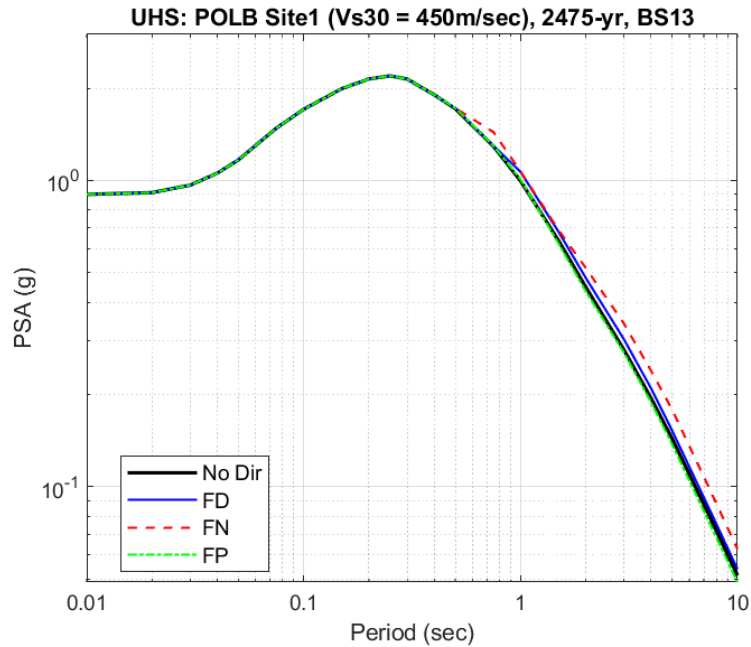


Figure 62. Uniform hazard spectra for Site 1 ($V_{s30} = 450$ m/sec) without directivity (black line) and with the BS13 directivity model for average horizontal (FD), fault normal (FN) and fault parallel (FP) components for the 2,475-year return period.

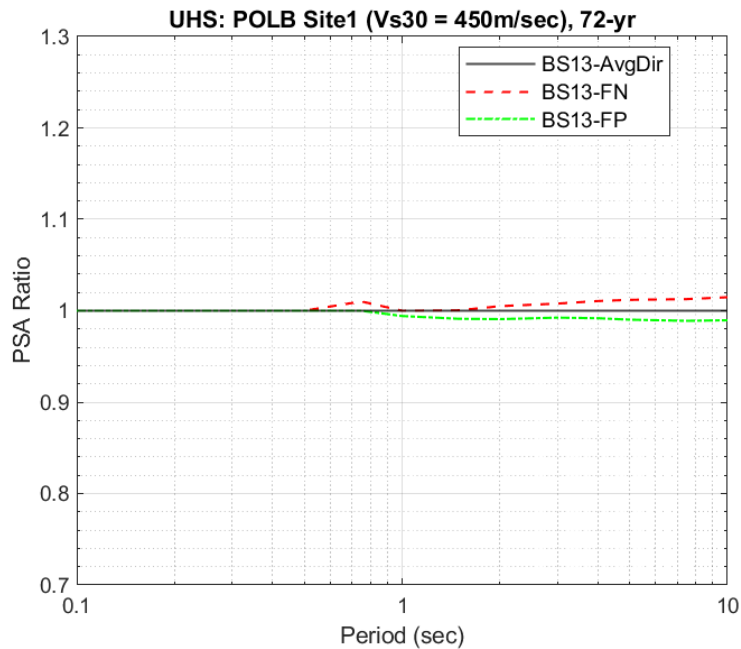


Figure 63. UHS spectral ratio for Site 1 ($V_{s30} = 450$ m/sec) for the 72-year return period hazard level for the individual horizontal components of the BS13 directivity models.

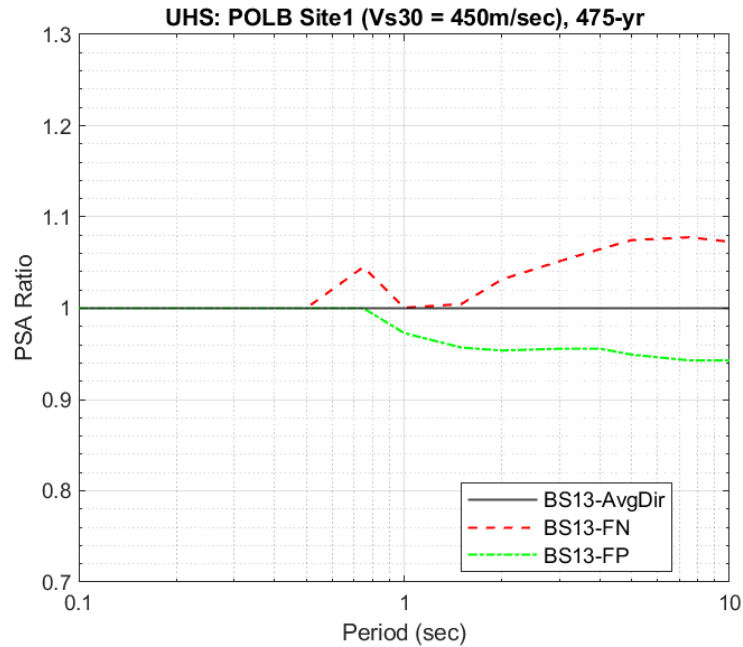


Figure 64. UHS spectral ratio for Site 1 ($V_{s30} = 450\text{ m/sec}$) for the 475-year return period hazard level for the individual horizontal components of the BS13 directivity models.

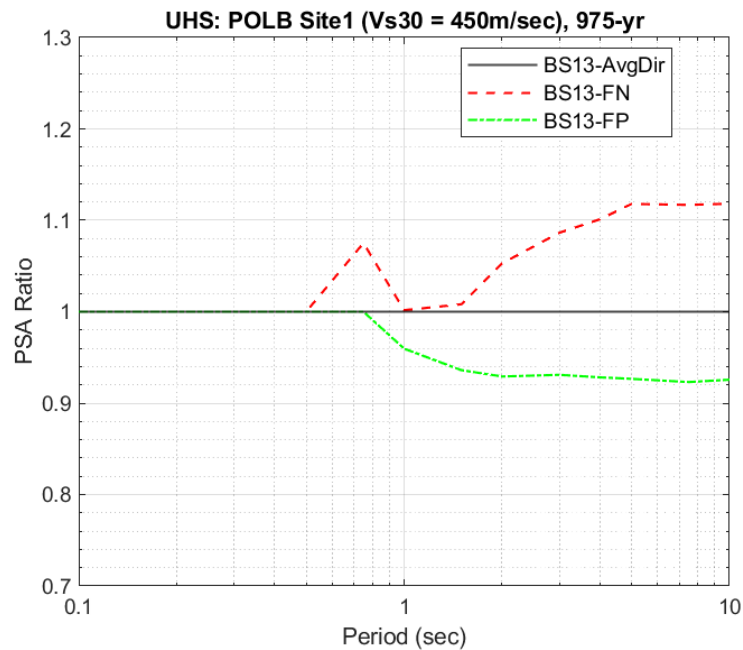


Figure 65. UHS spectral ratio for Site 1 ($V_{s30} = 450\text{ m/sec}$) for the 975-year return period hazard level for the individual horizontal components of the BS13 directivity models.

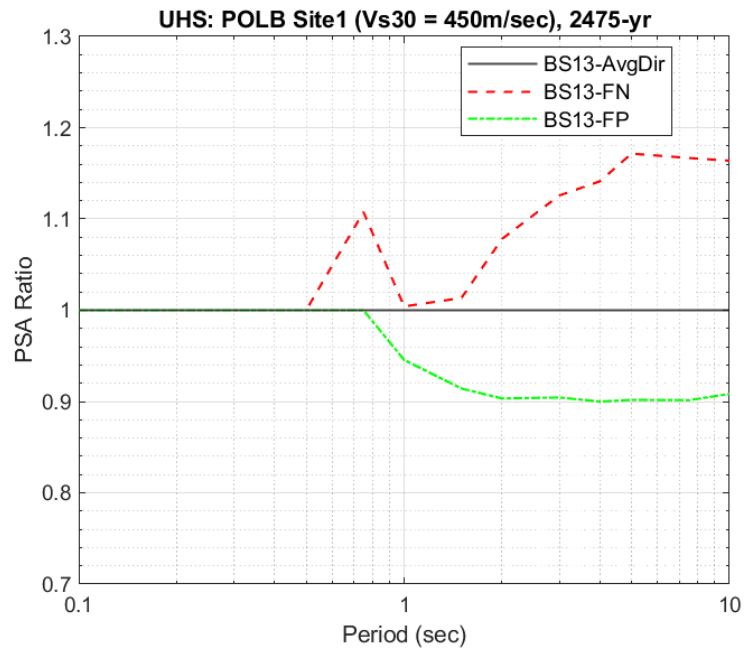


Figure 66. UHS spectral ratio for Site 1 ($V_{s30} = 450\text{ m/sec}$) for the 2,475-year return period hazard level for the individual horizontal components of the BS13 directivity models.

Table 12. Horizontal UHS for Site 1 ($V_{S30} = 450$ m/sec) at the four hazard levels with the inclusion of the BS13 directivity models for the average horizontal component.

Period (sec)	72-year Horizontal BS13 (FD) PSA (g)	475-year Horizontal BS13 (FD) PSA (g)	975-year Horizontal BS13 (FD) PSA (g)	2,475-year Horizontal BS13 (FD) PSA (g)
0.01	0.1535	0.4422	0.6189	0.9013
0.02	0.1545	0.4481	0.6273	0.9130
0.03	0.1647	0.4794	0.6675	0.9660
0.04	0.1823	0.5320	0.7363	1.0571
0.05	0.2019	0.5836	0.8158	1.1673
0.075	0.2580	0.7384	1.0235	1.4843
0.1	0.3077	0.8743	1.1945	1.7081
0.15	0.3600	1.0140	1.4119	1.9959
0.2	0.3680	1.0551	1.4932	2.1461
0.25	0.3560	1.0421	1.4959	2.1961
0.3	0.3364	0.9957	1.4424	2.1445
0.4	0.2867	0.8677	1.2576	1.9044
0.5	0.2474	0.7597	1.1153	1.7236
0.75	0.1726	0.5437	0.8188	1.2990
1	0.1269	0.4189	0.6497	1.0668
1.5	0.0783	0.2627	0.4096	0.6784
2	0.0540	0.1850	0.2893	0.4804
3	0.0321	0.1143	0.1804	0.3026
4	0.0217	0.0800	0.1259	0.2093
5	0.0157	0.0597	0.0930	0.1524
7.5	0.0088	0.0353	0.0531	0.0833
10	0.0055	0.0235	0.0350	0.0538

Table 13. Horizontal UHS for Site 1 ($V_{S30} = 450$ m/sec) at the four hazard levels with the inclusion of the BS13 directivity models for the fault normal (FN) component.

Period (sec)	72-year Horizontal BS13 (FN) PSA (g)	475-year Horizontal BS13 (FN) PSA (g)	975-year Horizontal BS13 (FN) PSA (g)	2,475-year Horizontal BS13 (FN) PSA (g)
0.01	0.1535	0.4422	0.6189	0.9013
0.02	0.1545	0.4481	0.6273	0.9130
0.03	0.1647	0.4794	0.6675	0.9660
0.04	0.1823	0.5320	0.7363	1.0571
0.05	0.2019	0.5836	0.8158	1.1673
0.075	0.2580	0.7384	1.0235	1.4843
0.1	0.3077	0.8743	1.1945	1.7081
0.15	0.3600	1.0140	1.4119	1.9959
0.2	0.3680	1.0551	1.4932	2.1461
0.25	0.3560	1.0421	1.4959	2.1961
0.3	0.3364	0.9957	1.4424	2.1445
0.4	0.2867	0.8677	1.2576	1.9044
0.5	0.2474	0.7597	1.1153	1.7236
0.75	0.1743	0.5683	0.8803	1.4388
1	0.1269	0.4191	0.6508	1.0713
1.5	0.0783	0.2639	0.4130	0.6875
2	0.0543	0.1908	0.3046	0.5180
3	0.0323	0.1202	0.1960	0.3407
4	0.0220	0.0852	0.1387	0.2388
5	0.0159	0.0642	0.1039	0.1785
7.5	0.0089	0.0380	0.0593	0.0971
10	0.0056	0.0252	0.0391	0.0626

Table 14. Horizontal UHS for Site 1 ($V_{s30} = 450$ m/sec) at the four hazard levels with the inclusion of the BS13 directivity models for the fault parallel (FP) component.

Period (sec)	72-year Horizontal BS13 (FP) PSA (g)	475-year Horizontal BS13 (FP) PSA (g)	975-year Horizontal BS13 (FP) PSA (g)	2,475-year Horizontal BS13 (FP) PSA (g)
0.01	0.1535	0.4422	0.6189	0.9013
0.02	0.1545	0.4481	0.6273	0.9130
0.03	0.1647	0.4794	0.6675	0.9660
0.04	0.1823	0.5320	0.7363	1.0571
0.05	0.2019	0.5836	0.8158	1.1673
0.075	0.2580	0.7384	1.0235	1.4843
0.1	0.3077	0.8743	1.1945	1.7081
0.15	0.3600	1.0140	1.4119	1.9959
0.2	0.3680	1.0551	1.4932	2.1461
0.25	0.3560	1.0421	1.4959	2.1961
0.3	0.3364	0.9957	1.4424	2.1445
0.4	0.2867	0.8677	1.2576	1.9044
0.5	0.2474	0.7597	1.1153	1.7236
0.75	0.1726	0.5437	0.8188	1.2990
1	0.1262	0.4075	0.6235	1.0088
1.5	0.0776	0.2514	0.3834	0.6203
2	0.0535	0.1764	0.2688	0.4340
3	0.0318	0.1093	0.1680	0.2737
4	0.0216	0.0765	0.1169	0.1883
5	0.0156	0.0567	0.0861	0.1374
7.5	0.0087	0.0333	0.0490	0.0751
10	0.0055	0.0221	0.0324	0.0489

4.3 Site 3 Results

4.3.1 Site 3 Results without Directivity, $V_{s30} = 450$ m/sec

The mean hazard curves including the Wilmington fault for Site 3 are shown in Figures 67 through 70 for PGA and spectral periods of 0.2, 1, and 3 sec. For the longer spectral periods (i.e., 1 and 3 sec), these plots show the horizontal component without the inclusion of the directivity models. In these plots, individual hazard curves from the scenario fault ruptures from the UCERF3 faults, gridded sources, the Wilmington fault as well as the combined total hazard are presented. Hazard levels corresponding to the 475 and 2,475-year return periods are also plotted in the figures. For the short to intermediate spectral periods, the hazard is equally

controlled by the UCERF3 grid and fault sources for hazard levels of about 100 to 200 years. For shorter return periods and the intermediate to short periods, the hazard is controlled by the gridded source. For longer return periods and as well longer spectral periods, the hazard is controlled by the UCERF3 fault sources. For all cases, the contribution from the Wilmington fault is less than from the other UCERF3 sources.

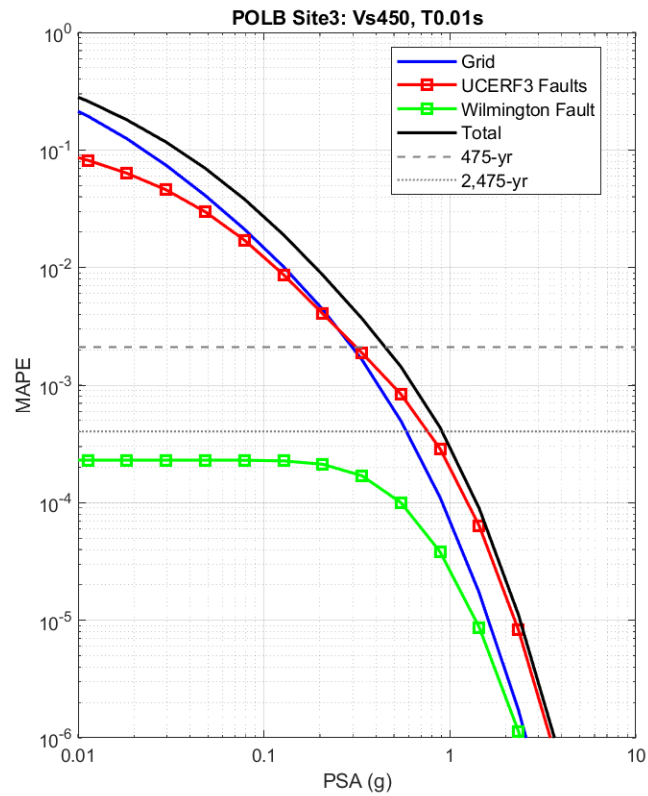


Figure 67. Mean horizontal component hazard curves from the UCERF3 gridded and fault sources, Wilmington fault, and total mean hazard for PGA for Site 3 for $V_{s30} = 450$ m/sec without directivity. MAPE refers to mean annual probability of exceedance.

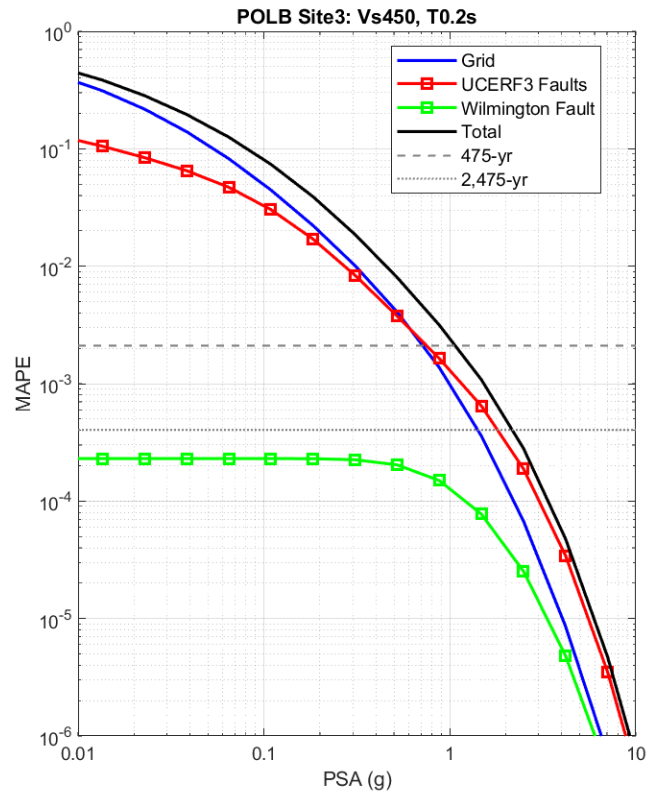


Figure 68. Mean horizontal component hazard curves from the UCERF3 gridded and fault sources, Wilmington fault, and total mean hazard for $T=0.2$ sec for Site 3 for $V_{S30} = 450$ m/sec without directivity. MAPE refers to mean annual probability of exceedance.

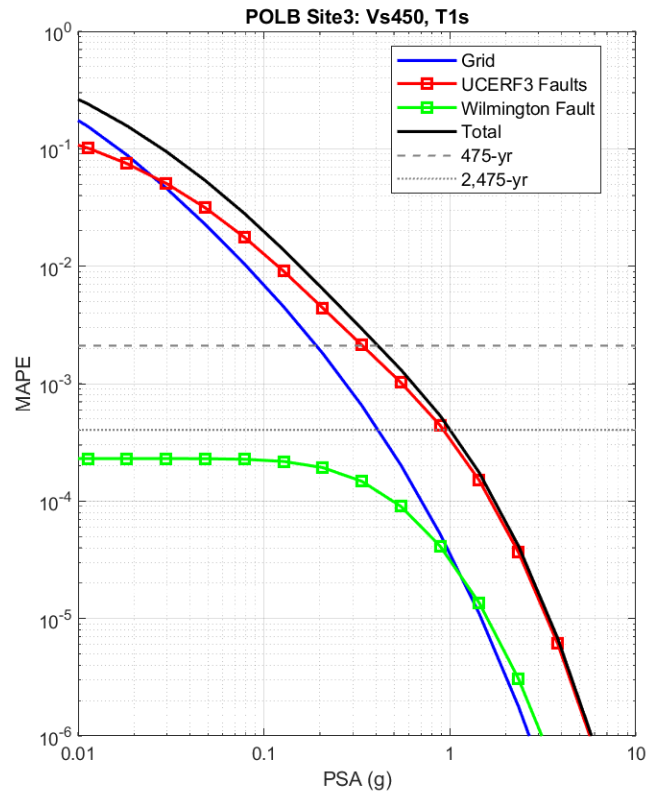


Figure 69. Mean horizontal component hazard curves from the UCERF3 gridded and fault sources, Wilmington fault, and total mean hazard for $T=1.0$ sec for Site 3 for $V_{s30} = 450$ m/sec without directivity. MAPE refers to mean annual probability of exceedance.

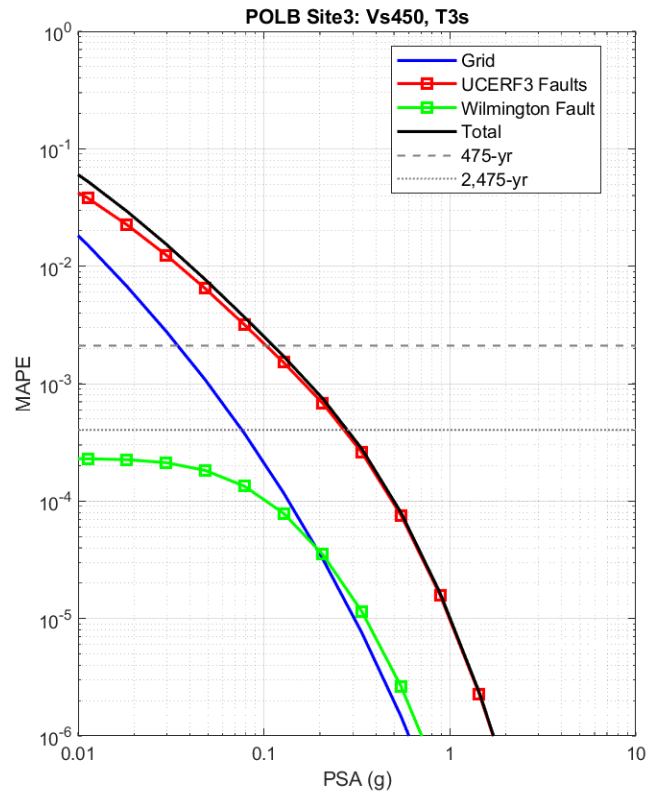


Figure 70. Mean horizontal component hazard curves from the UCERF3 gridded and fault sources, Wilmington fault, and total mean hazard for $T=3.0$ sec for Site 3 for $V_{s30} = 450$ m/sec without directivity. MAPE refers to mean annual probability of exceedance.

To further illustrate the contribution from the parent fault systems from the UCERF3 database and the Wilmington fault, the ranked top 15 contributing parent fault hazard curves at the 2,475-year hazard level are plotted along with the total combined hazard curve from just fault sources including the Wilmington fault. These results are plotted in Figures 71 through 74 for the same previous four spectral periods. Note that given the change in the relative ranking order the line and symbol type for a given parent fault varies from one plot to another. The largest contributing parent fault system to the total fault hazard is the Palos Verdes fault which is an expected result given the close distance to the site and the assigned slip rate for this fault relative to the other faults in the area. The Wilmington fault has a similar contribution as the Compton fault for the intermediate and short periods and a lesser contribution at the longer spectral periods.

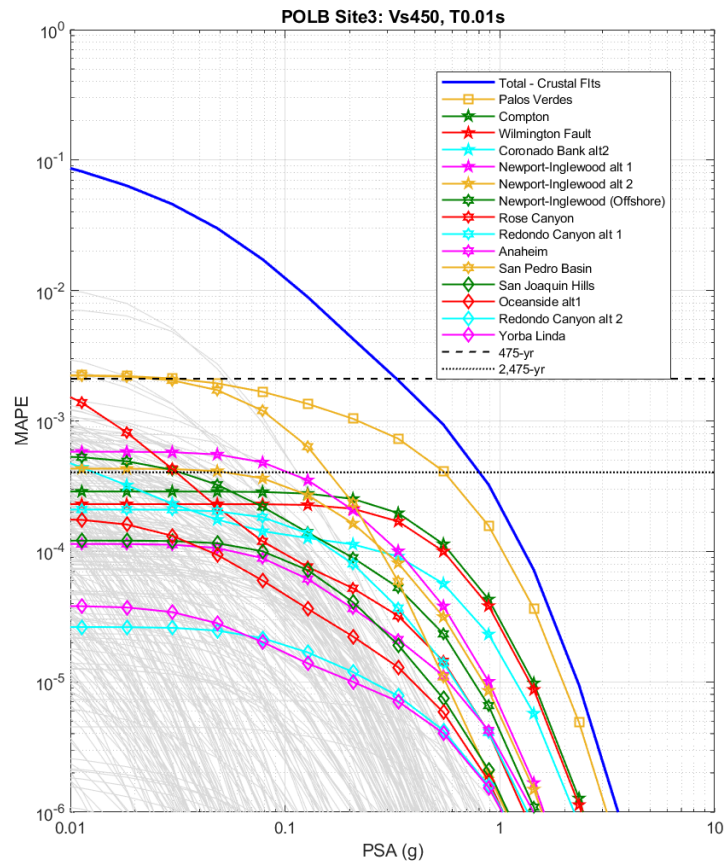


Figure 71. Mean horizontal component hazard curves from the Wilmington and UCERF3 parent fault sources at PGA for Site 3 for $V_{s30} = 450$ m/sec without directivity. The colored individual-fault hazard curves show the top contributing parent faults to the total hazard from crustal faults. MAPE refers to mean annual probability of exceedance.

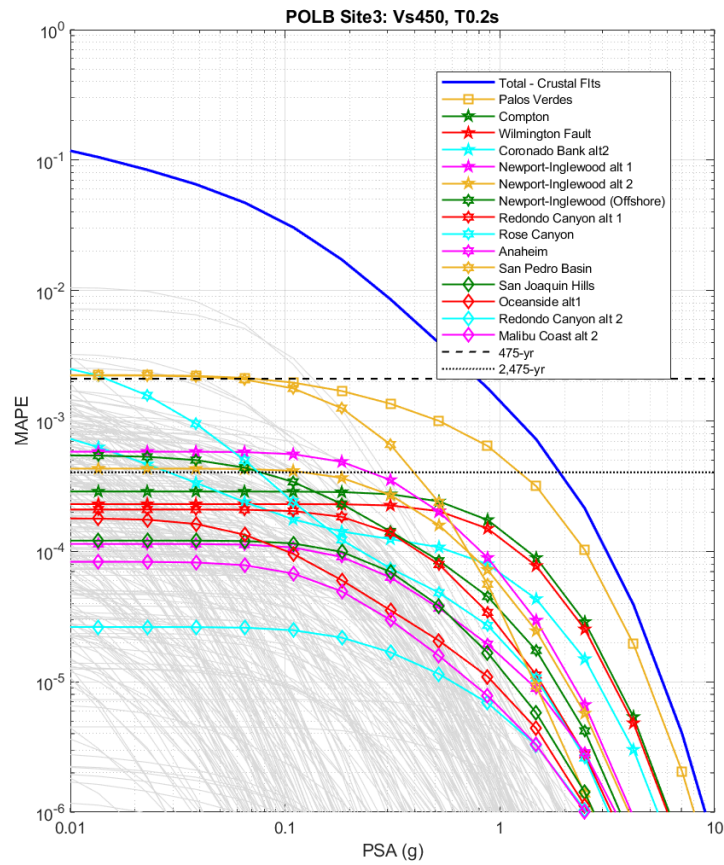


Figure 72. Mean horizontal component hazard curves from the Wilmington and UCERF3 parent fault sources at $T=0.2$ sec for Site 3 for $V_{s30} = 450$ m/sec without directivity. The colored individual-fault hazard curves show the top contributing parent faults to the total hazard from crustal faults. MAPE refers to mean annual probability of exceedance.

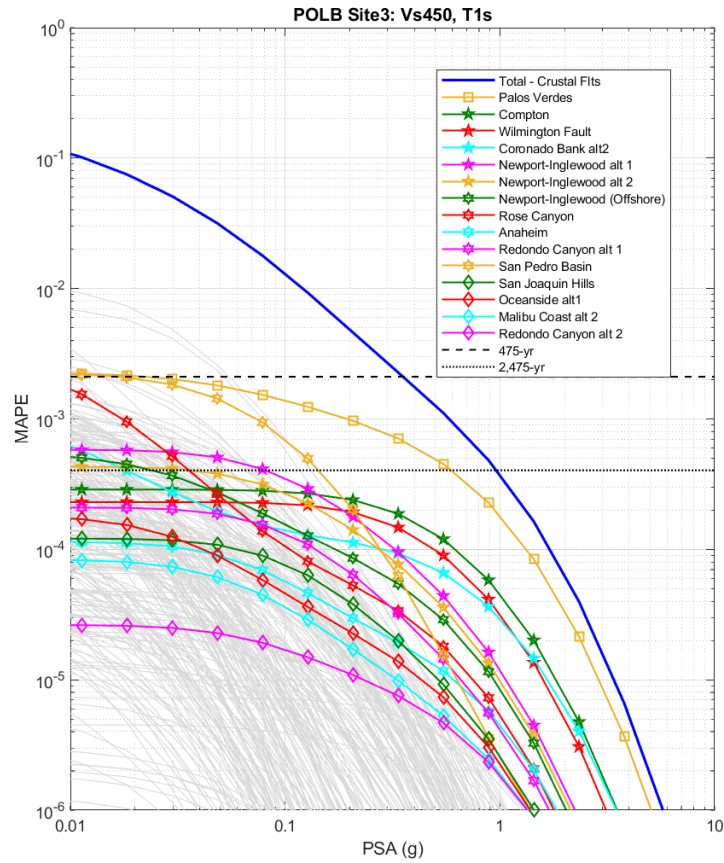


Figure 73. Mean horizontal component hazard curves from the Wilmington and UCERF3 parent fault sources at $T=1.0$ sec for Site 3 for $V_{s30} = 450$ m/sec without directivity. The colored individual-fault hazard curves show the top contributing parent faults to the total hazard from crustal faults. MAPE refers to mean annual probability of exceedance.

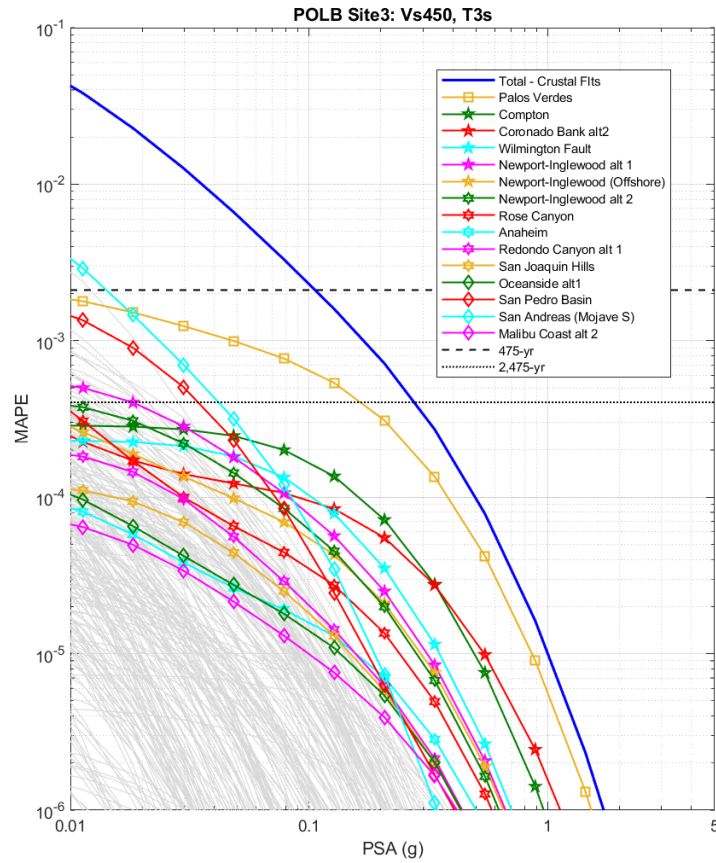


Figure 74. Mean horizontal component hazard curves from the Wilmington and UCERF3 parent fault sources at $T=3.0$ sec for Site 3 for $V_{s30} = 450$ m/sec without directivity. The colored individual-fault hazard curves show the top contributing parent faults to the total hazard from crustal faults. MAPE refers to mean annual probability of exceedance.

Given the hazard curves for the full suite of spectral periods, the computed uniform hazard spectra (UHS) for the selected 72, 475, 975 and 2,475-year return period hazard levels are plotted in Figure 75 for the average horizontal component without the inclusion of the directivity models. These horizontal UHS values for the return period hazard levels at all spectral periods are given in Table 15.

Table 15. Horizontal UHS for Site 3 ($V_{S30} = 450$ m/sec) at the suite of hazard levels without the inclusion of the directivity models.

Period (sec)	72-year Horizontal PSA (g)	475-year Horizontal PSA (g)	975-year Horizontal PSA (g)	2,475-year Horizontal PSA (g)
0.01	0.1552	0.4482	0.6250	0.9064
0.02	0.1562	0.4542	0.6335	0.9182
0.03	0.1665	0.4861	0.6743	0.9718
0.04	0.1844	0.5397	0.7443	1.0639
0.05	0.2042	0.5907	0.8252	1.1754
0.075	0.2609	0.7478	1.0336	1.4941
0.1	0.3114	0.8858	1.2071	1.7205
0.15	0.3639	1.0257	1.4277	2.0098
0.2	0.3719	1.0679	1.5072	2.1614
0.25	0.3598	1.0552	1.5101	2.2119
0.3	0.3399	1.0087	1.4602	2.1597
0.4	0.2898	0.8800	1.2719	1.9158
0.5	0.2499	0.7679	1.1229	1.7257
0.75	0.1743	0.5496	0.8246	1.2987
1	0.1273	0.4100	0.6233	1.0000
1.5	0.0786	0.2574	0.3934	0.6359
2	0.0542	0.1815	0.2778	0.4492
3	0.0322	0.1118	0.1720	0.2798
4	0.0218	0.0786	0.1203	0.1945
5	0.0158	0.0586	0.0895	0.1437
7.5	0.0088	0.0346	0.0513	0.0794
10	0.0055	0.0229	0.0338	0.0515

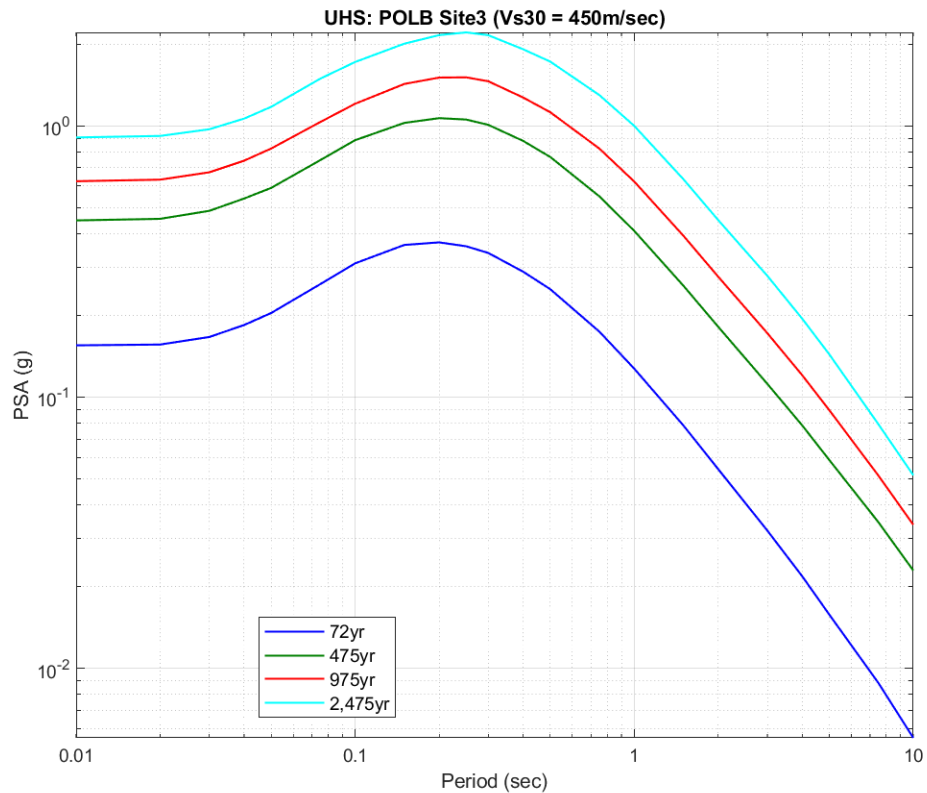


Figure 75. Uniform hazard spectra for Site 3 ($V_{s30} = 450$ m/sec) without the inclusion of the directivity model.

The mean magnitude, distance, and epsilon values for the horizontal component without the directivity models are plotted in Figures 76 to 78 for the selected four hazard levels. These results are plotted as a function of spectral period. In general, the magnitude increases with the increasing return period and spectral periods. For the mean distance values, the distances also decrease as a function of increasing return period but are larger for the longer spectral period given the greater distance to the larger magnitude faults in the region (e.g., San Andreas fault). Finally, the mean epsilon values increase as a function of increasing return periods with the results for the 2,475-year greater than approximately 1 over most of the spectral period range. The mean magnitude, distance, and epsilon values are listed in Tables 16 through 18 for the four hazard levels.

Table 16. Mean magnitude for the four hazard levels for Site 3 ($V_{S30} = 450$ m/sec) without the inclusion of the directivity models.

Period (sec)	72-year Magnitude	475-year Magnitude	975-year Magnitude	2,475-year Magnitude
0.01	6.37	6.61	6.73	6.84
0.02	6.37	6.61	6.72	6.84
0.03	6.35	6.60	6.71	6.82
0.04	6.35	6.60	6.69	6.80
0.05	6.33	6.57	6.67	6.76
0.075	6.30	6.52	6.62	6.73
0.1	6.28	6.52	6.60	6.69
0.15	6.30	6.54	6.66	6.74
0.2	6.34	6.60	6.72	6.81
0.25	6.39	6.65	6.78	6.88
0.3	6.43	6.70	6.83	6.92
0.4	6.52	6.80	6.90	7.00
0.5	6.58	6.85	6.94	7.04
0.75	6.69	6.95	7.03	7.11
1	6.77	7.00	7.08	7.15
1.5	6.91	7.12	7.16	7.21
2	6.98	7.19	7.22	7.25
3	7.11	7.28	7.30	7.31
4	7.19	7.36	7.35	7.36
5	7.23	7.41	7.41	7.40
7.5	7.32	7.52	7.53	7.52
10	7.36	7.57	7.59	7.59

Table 17. Mean distance for the four hazard levels for Site 3 ($V_{S30} = 450$ m/sec) without inclusion of the directivity models.

Period (sec)	72-year Distance (km)	475-year Distance (km)	975-year Distance (km)	2,475-year Distance (km)
0.01	26.56	9.96	7.00	5.04
0.02	26.44	9.81	6.93	5.02
0.03	26.32	9.76	7.13	5.19
0.04	25.99	9.38	7.28	5.42
0.05	25.59	9.99	7.35	5.70
0.075	25.89	10.80	8.02	5.94
0.1	25.42	10.30	8.34	6.38
0.15	25.89	10.88	7.86	6.29
0.2	26.73	11.11	7.64	6.00
0.25	27.77	11.27	7.58	5.78
0.3	29.00	11.55	7.62	5.75
0.4	31.78	11.87	8.55	5.82
0.5	34.74	13.63	9.16	5.85
0.75	39.59	15.02	9.72	6.07
1	41.53	16.83	10.29	6.08
1.5	47.68	20.09	12.31	7.06
2	52.14	22.10	13.95	8.03
3	57.83	25.34	16.03	9.00
4	61.62	27.48	17.92	10.26
5	64.05	31.44	21.29	12.82
7.5	72.25	41.95	33.56	25.09
10	78.09	48.53	41.43	34.18

Table 18. Mean epsilon for the four hazard levels for Site 3 ($V_{S30} = 450$ m/sec) without inclusion of the directivity models.

Period (sec)	72-year Epsilon	475-year Epsilon	975-year Epsilon	2,475-year Epsilon
0.01	0.07	0.49	0.75	1.16
0.02	0.07	0.49	0.75	1.17
0.03	0.09	0.52	0.77	1.17
0.04	0.12	0.55	0.81	1.18
0.05	0.16	0.59	0.85	1.20
0.075	0.20	0.67	0.92	1.29
0.1	0.23	0.72	0.96	1.29
0.15	0.20	0.67	0.93	1.26
0.2	0.18	0.61	0.85	1.18
0.25	0.17	0.55	0.78	1.13
0.3	0.19	0.53	0.76	1.09
0.4	0.20	0.49	0.71	1.06
0.5	0.22	0.48	0.68	1.04
0.75	0.25	0.46	0.65	1.00
1	0.25	0.43	0.60	0.97
1.5	0.22	0.41	0.58	0.95
2	0.17	0.40	0.58	0.94
3	0.09	0.37	0.56	0.91
4	-0.01	0.36	0.57	0.93
5	-0.08	0.37	0.59	0.94
7.5	-0.20	0.45	0.73	1.09
10	-0.30	0.44	0.76	1.14

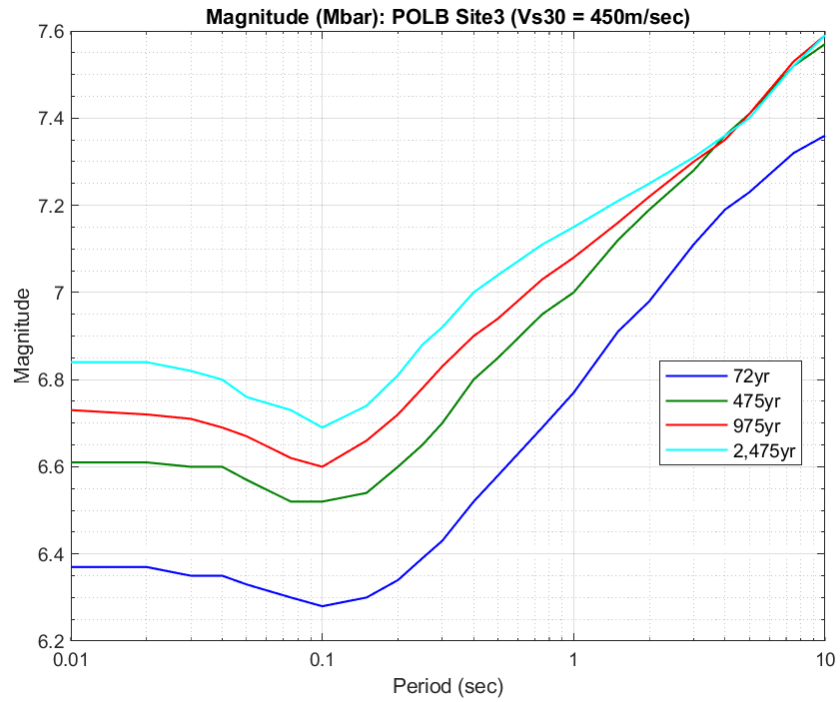


Figure 76. Horizontal mean magnitude for Site 3 ($V_{s30} = 450\text{ m/sec}$) without the inclusion of the directivity models.

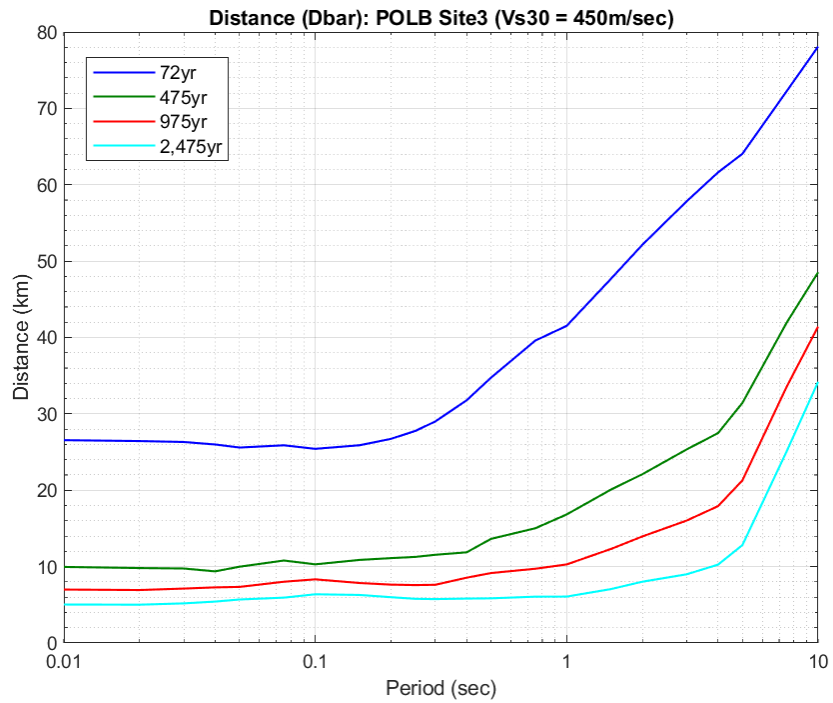


Figure 77. Horizontal mean distance for Site 3 ($V_{s30} = 450\text{ m/sec}$) without the inclusion of the directivity models.

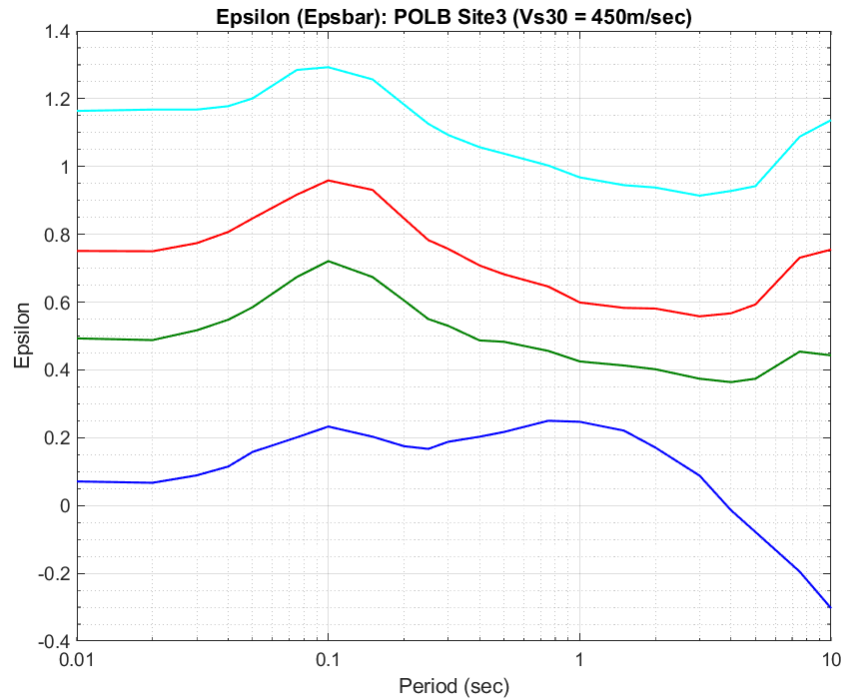


Figure 78. Horizontal mean epsilon for Site 3 ($V_{s30} = 450$ m/sec) without the inclusion of the directivity models.

The binned magnitude and distance contributions to the 72-year hazard level are shown in Figures 79 to 82 for Site 3 ($V_{s30} = 450$ m/sec) for PGA and spectral periods of 0.2, 1.0, and 3.0 sec. Similar plots are shown in Figures 83 to 86 for the 475-year hazard level, Figures 87 to 90 for the 975-year hazard level, and Figures 91 to 94 for the 2,475-year hazard level.

At the shortest return period level of 72 years, the hazard is being contributed to from small to moderate magnitude events over a broad distance of less than about 100 km. At the longer spectral periods, a relative increase in the contribution to the total hazard is observed for the larger magnitude (i.e., greater than 7.0) in the distance bin of 50 – 100 km. This corresponds to the contribution from the San Andreas and San Jacinto faults with their relatively higher slip rates. At the longer return period hazard levels, the relative increased contribution of the local faults to the total hazard is observed in the deaggregation plots with the majority of the contribution from sources with distance less than about 50 km. Based on this increased contribution from these local faults, the relative contribution from the San Andreas fault is decreased even at the longer spectral periods.

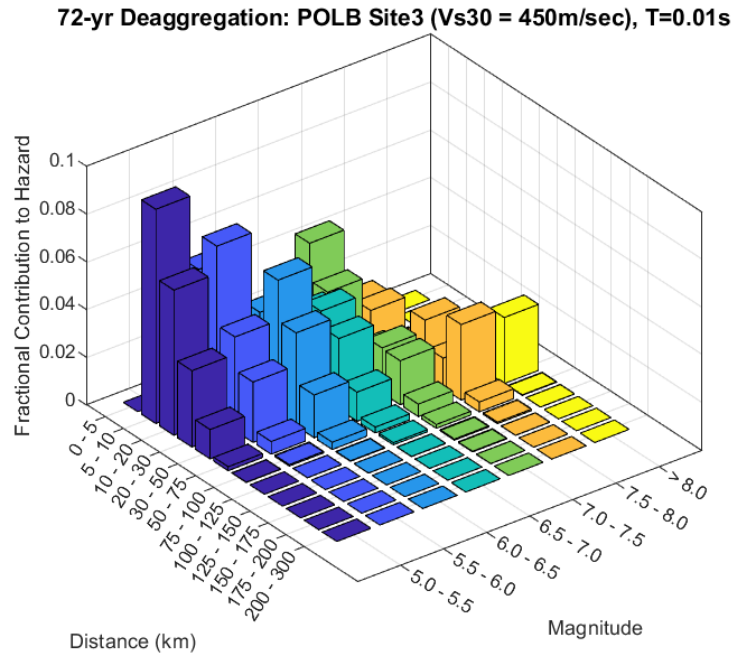


Figure 79. Magnitude-distance contribution for the 72-year hazard level for PGA for Site 3 ($V_{s30} = 450$ m/sec).

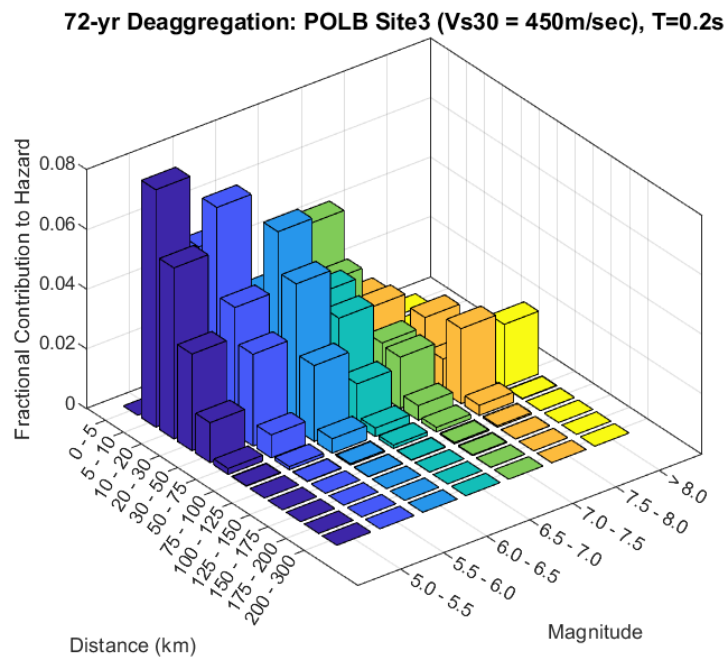


Figure 80. Magnitude-distance contribution for the 72-year hazard level for $T = 0.2$ sec for Site 3 ($V_{s30} = 450$ m/sec).

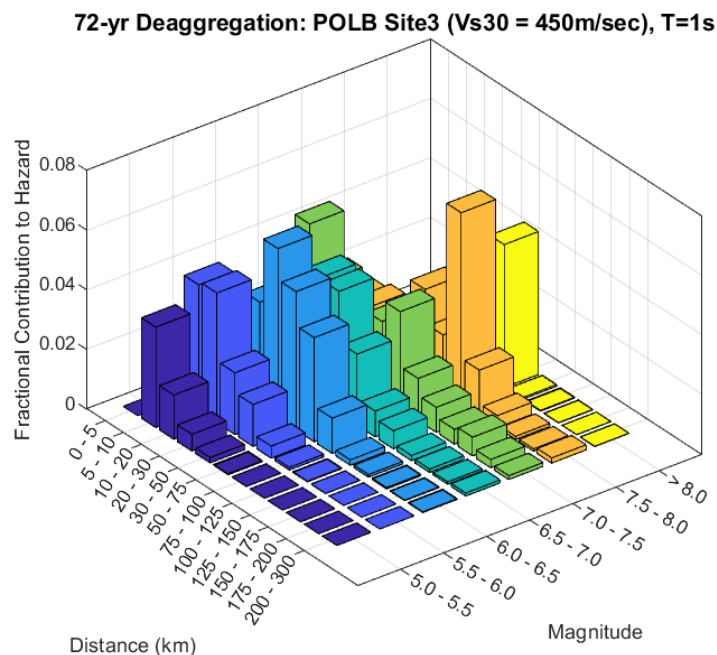


Figure 81. Magnitude-distance contribution for the 72-year hazard level for $T = 1.0$ sec for Site 3 ($V_{s30} = 450$ m/sec).

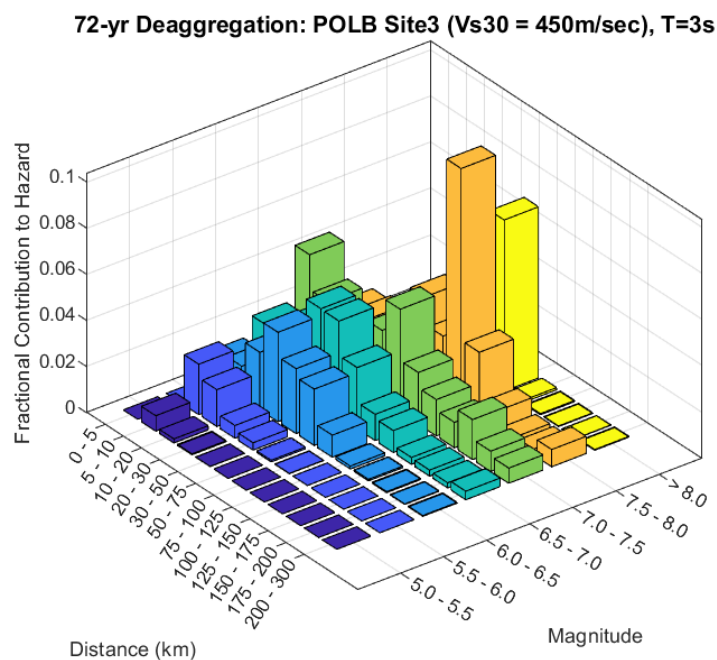


Figure 82. Magnitude-distance contribution for the 72-year hazard level for $T = 3.0$ sec for Site 3 ($V_{s30} = 450$ m/sec).

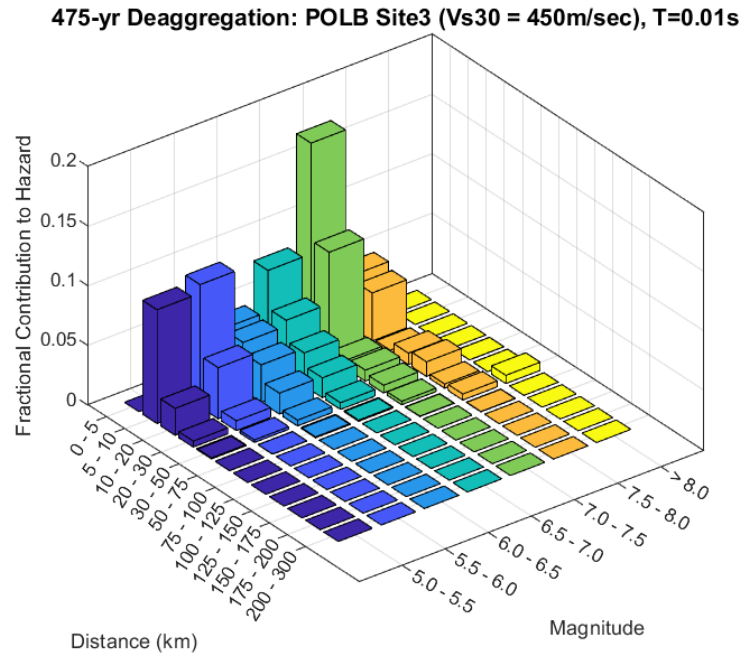


Figure 83. Magnitude-distance contribution for the 475-year hazard level for PGA for Site 3 ($V_{s30} = 450$ m/sec).

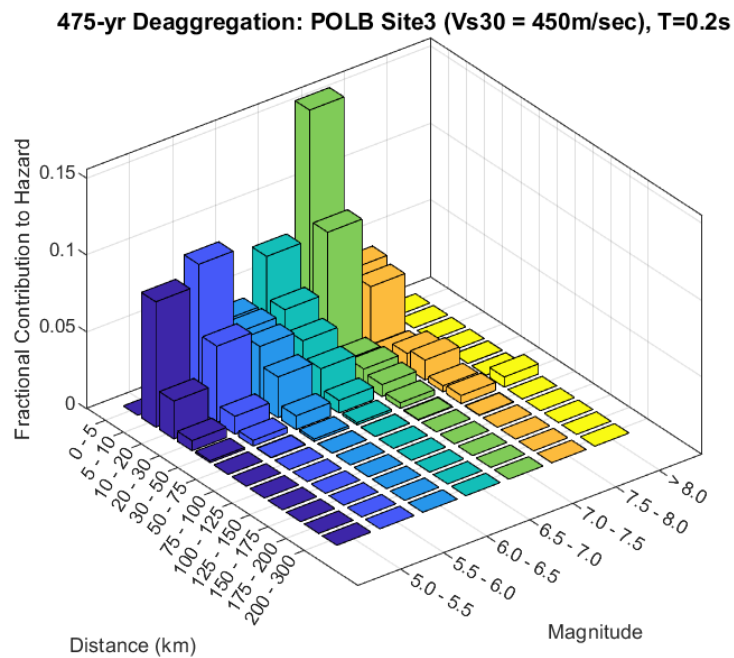


Figure 84. Magnitude-distance contribution for the 475-year hazard level for $T = 0.2$ sec for Site 3 ($V_{s30} = 450$ m/sec).

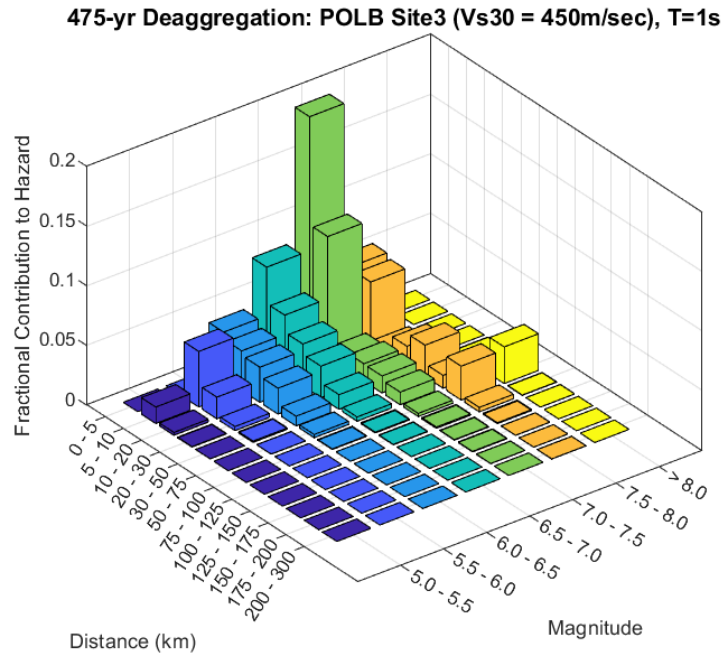


Figure 85. Magnitude-distance contribution for the 475-year hazard level for T = 1.0 sec for Site 3 ($V_{s30} = 450$ m/sec).

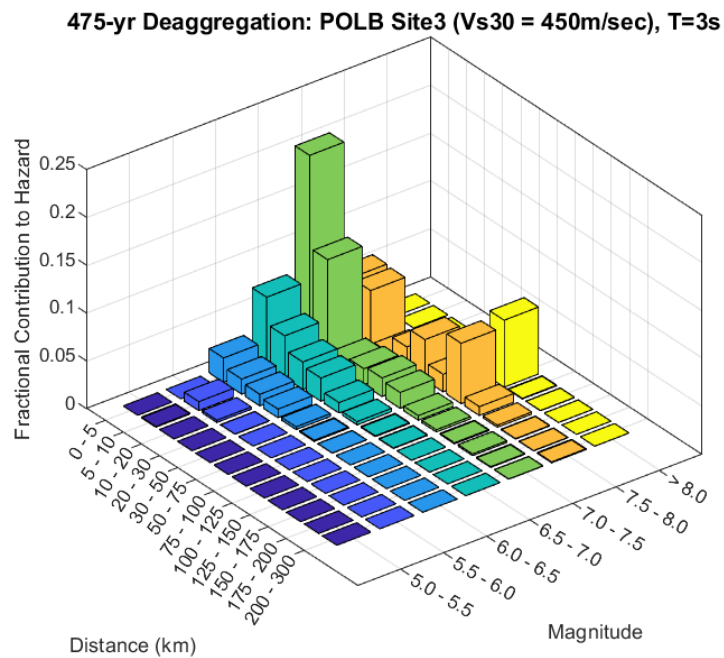


Figure 86. Magnitude-distance contribution for the 475-year hazard level for T = 3.0 sec for Site 3 ($V_{s30} = 450$ m/sec).

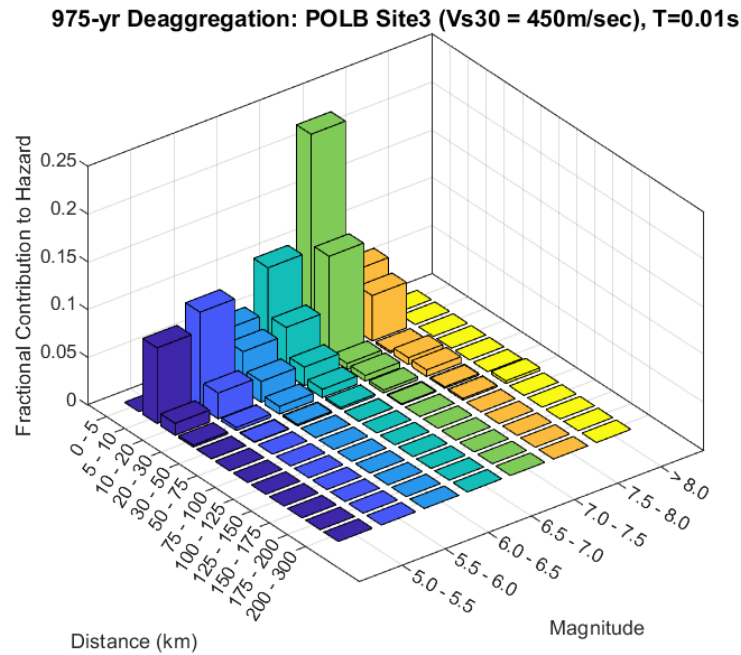


Figure 87. Magnitude-distance contribution for the 975-year hazard level for PGA for Site 3 ($V_{s30} = 450$ m/sec).

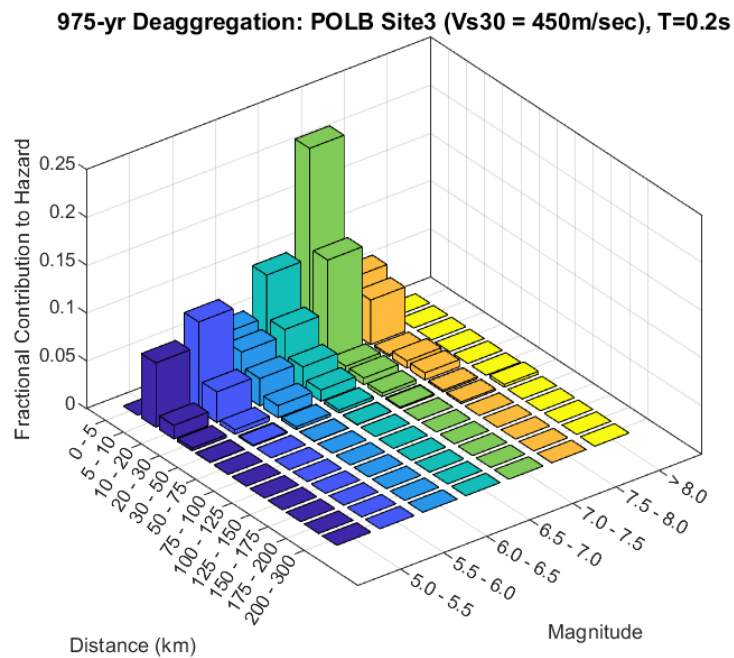


Figure 88. Magnitude-distance contribution for the 975-year hazard level for $T = 0.2$ sec for Site 3 ($V_{s30} = 450$ m/sec).

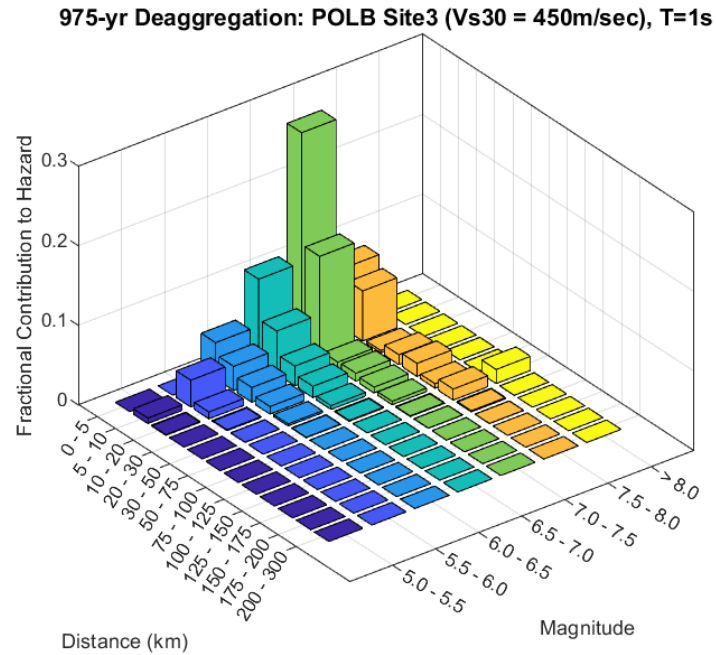


Figure 89. Magnitude-distance contribution for the 975-year hazard level for T = 1.0 sec for Site 3 ($V_{s30} = 450$ m/sec).

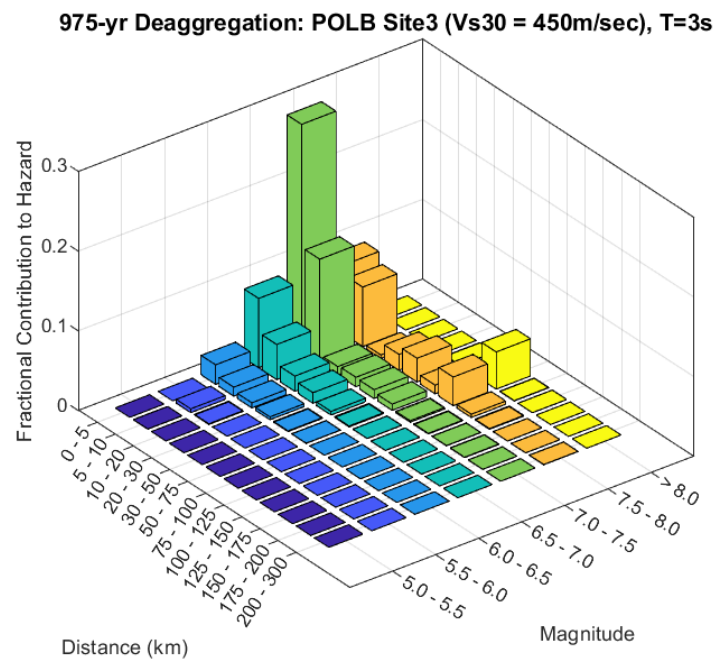


Figure 90. Magnitude-distance contribution for the 975-year hazard level for T = 3.0 sec for Site 3 ($V_{s30} = 450$ m/sec).

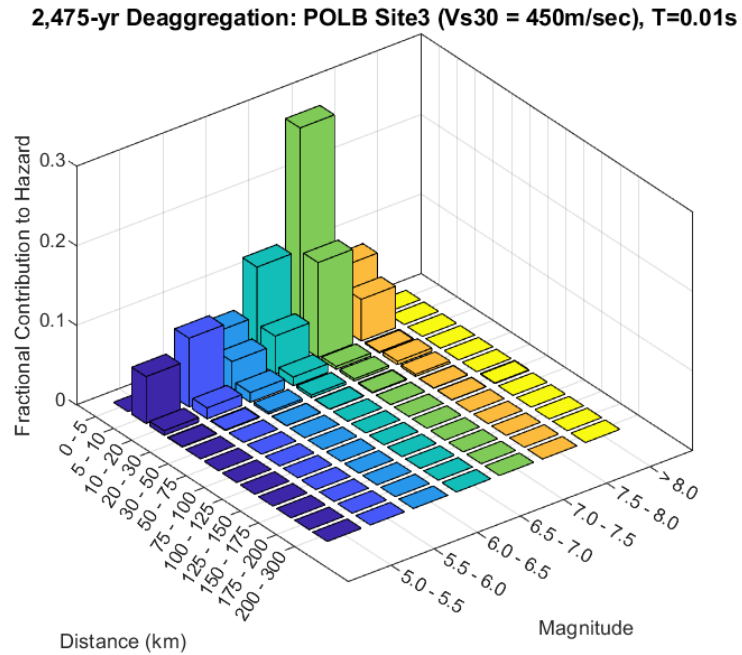


Figure 91. Magnitude-distance contribution for the 2,475-year hazard level for PGA for Site 3 ($V_{s30} = 450$ m/sec).

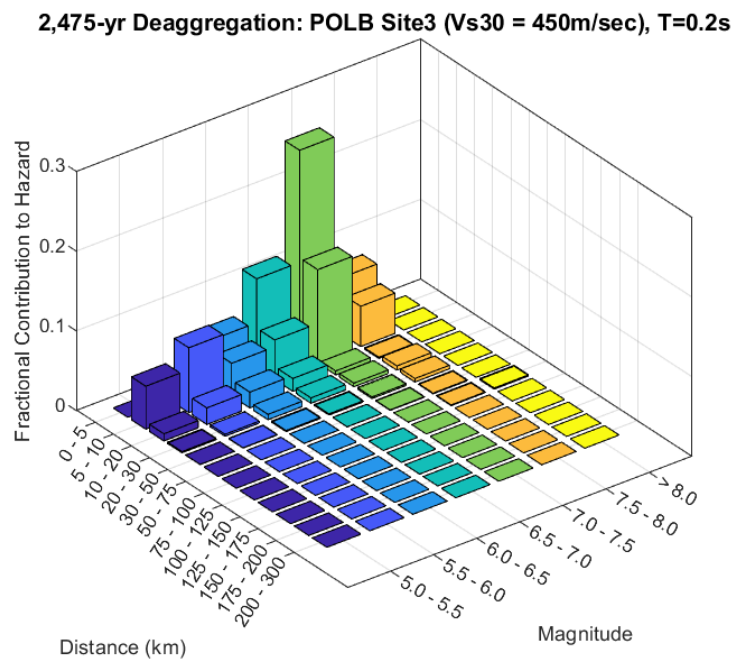


Figure 92. Magnitude-distance contribution for the 2,475-year hazard level for $T = 0.2$ sec for Site 3 ($V_{s30} = 450$ m/sec).

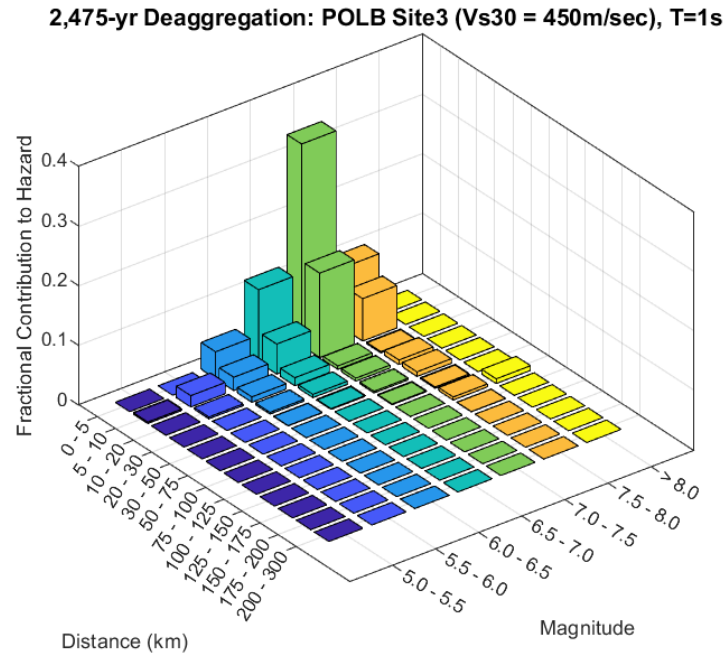


Figure 93. Magnitude-distance contribution for the 2,475-year hazard level for $T = 1.0$ sec for Site 3 ($V_{s30} = 450$ m/sec).

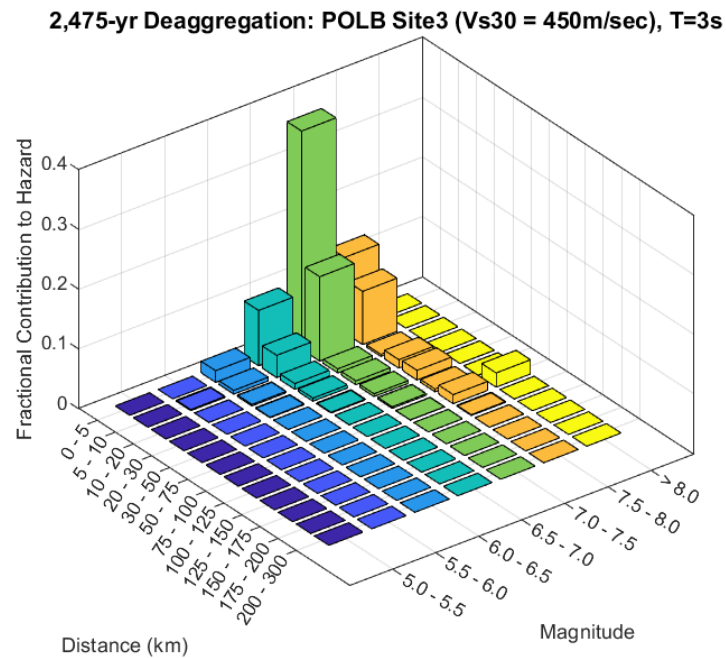


Figure 94. Magnitude-distance contribution for the 2,475-year hazard level for $T = 3.0$ sec for Site 3 ($V_{s30} = 450$ m/sec).

The hazard results for this site are not compared to results from the NSHM 2018 (NSHM18) and the NSHM 2023 (NSHM23). Given the proximity of the study sites, similar observations and trends are expected compared to the NSHMs results to those discussed in Section 4.2.1 for Site 1.

4.3.2 Site 3 Results with Directivity, $V_{S30} = 450$ m/sec

The results for Site 3 with $V_{S30} = 450$ m/sec with the inclusion of the directivity models are presented in this section. Note that the adjustments based on the directivity models only impact the longer spectral period ground motions (i.e., periods equal to and greater than 0.5 sec) and the results presented earlier for the shorter periods are unaffected by the directivity models. The mean total hazard curves for spectral periods of 1.0, 3.0, 5.0 and 10.0 seconds are plotted in Figures 95 through 98. In each plot, the individual hazard curves for each directivity model are plotted along with the weighted mean (dashed light blue line) using the assigned weights for the suite of directivity models. For comparison the mean hazard curve without directivity is also plotted (heavy black line).

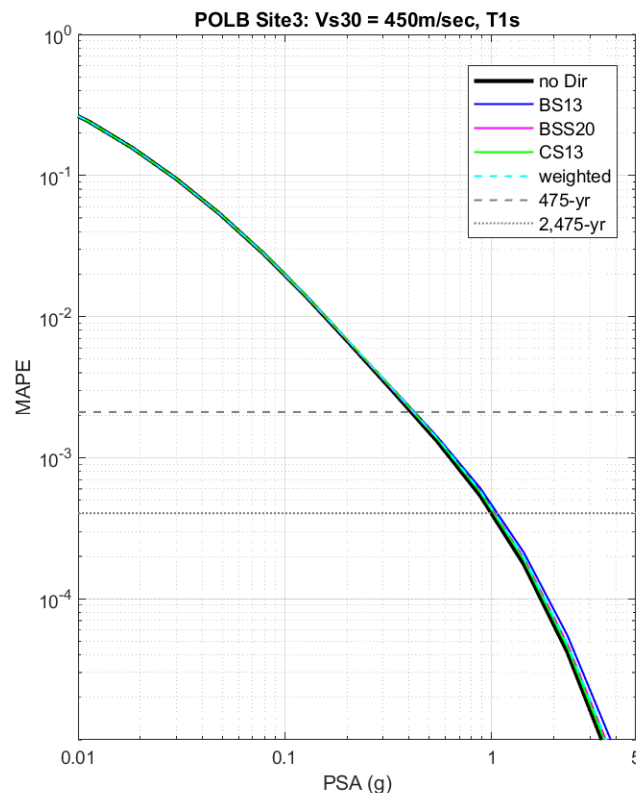


Figure 95. Total mean hazard curves without directivity (heavy black line), individual directivity models and weighted directivity results (dashed blue line) for Site 3 ($V_{S30} = 450$ m/sec) for $T=1.0$ sec spectral period. MAPE refers to mean annual probability of exceedance.

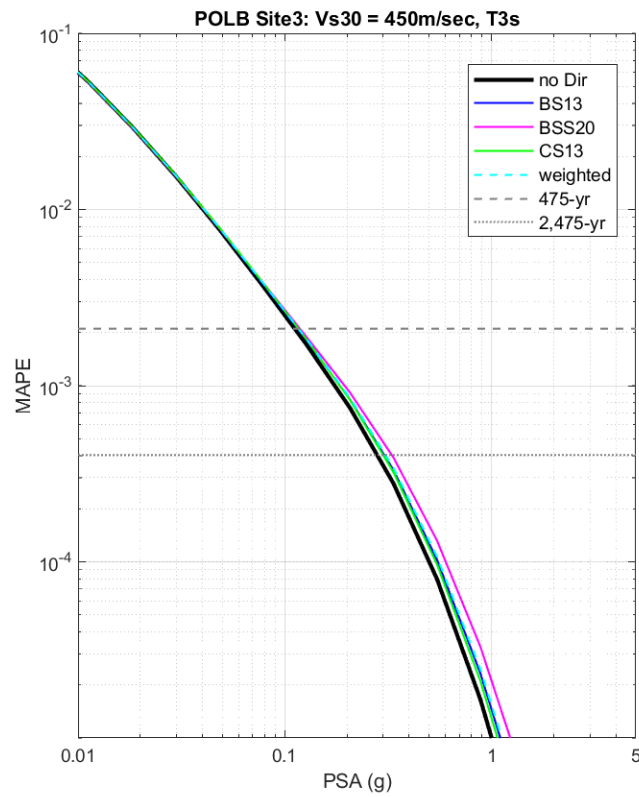


Figure 96. Total mean hazard curves without directivity (heavy black line), individual directivity models and weighted directivity results (dashed blue line) for Site 3 ($V_{s30} = 450$ m/sec) for $T=3.0$ sec spectral period. MAPE refers to mean annual probability of exceedance.

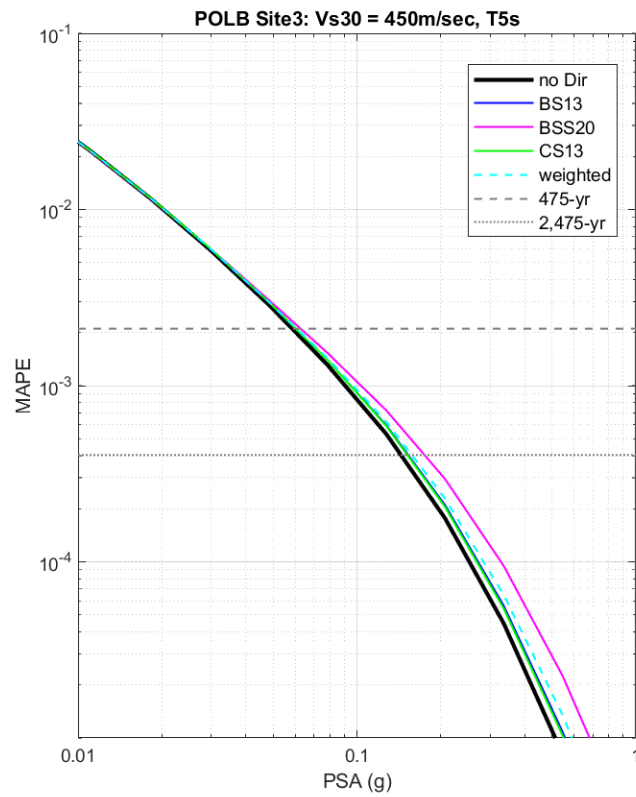


Figure 97. Total mean hazard curves without directivity (heavy black line), individual directivity models and weighted directivity results (dashed blue line) for Site 3 ($V_{S30} = 450$ m/sec) for $T=5.0$ sec spectral period. MAPE refers to mean annual probability of exceedance.

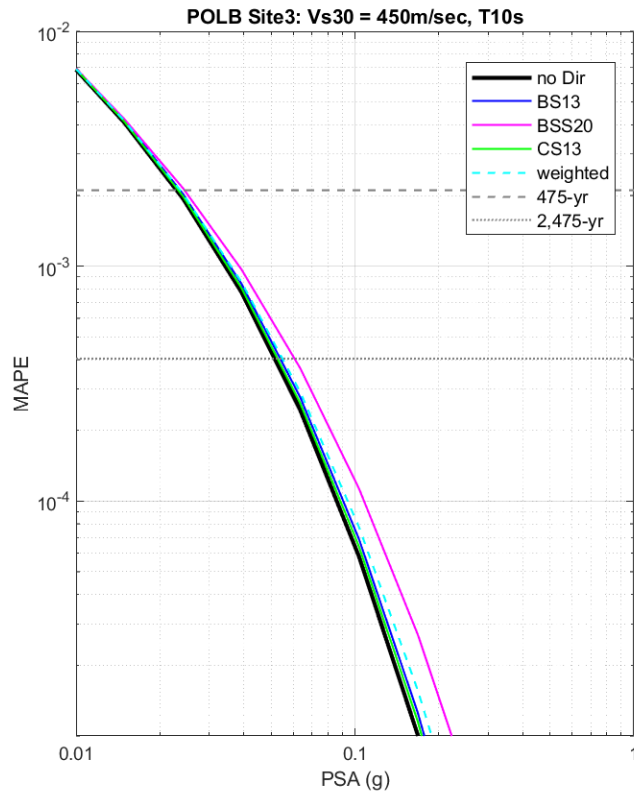


Figure 98. Total mean hazard curves without directivity (heavy black line), individual directivity models and weighted directivity results (dashed blue line) for Site 3 ($V_{s30} = 450$ m/sec) for $T=10.0$ sec spectral period. MAPE refers to mean annual probability of exceedance.

All of the directivity models show an increase in the hazard with the BSS20 model yielding the largest increase. To observe the impact on the ground motions from these directivity models, spectral ratios of the UHS ground motions are computed and plotted in Figure 99 through 102 for the selected four hazard levels. At the 72-year hazard level, there is minimal impact from the directivity models. For the longer return period levels, the results from the directivity models increase, especially for the longer spectral periods, beyond the period range of interest for this project. The UHS including the weighting combination of the directivity models for the four return period levels are listed in Table 19. The comparison of the UHS both with and without the directivity models are plotted in Figures 103 through 106 for the selected four hazard levels. Overall, the increase in the long-period ground motion due to directivity effects is observed to be 10% or less for the weighted directivity models. Similar deaggregation results are observed for the directivity cases and are not presented in the report.

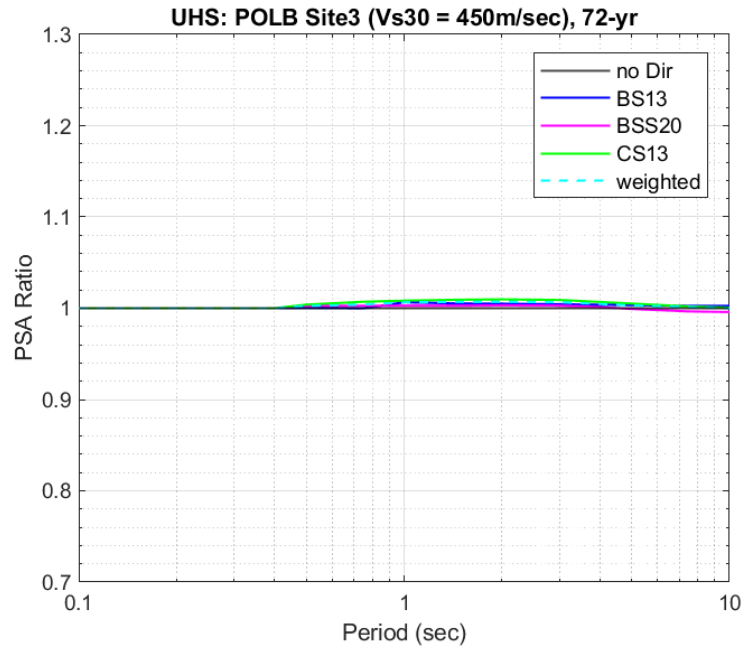


Figure 99. UHS spectral ratio for Site 3 ($V_{s30} = 450\text{ m/sec}$) for the 72-year return period hazard level for the individual and weighted combination directivity models.

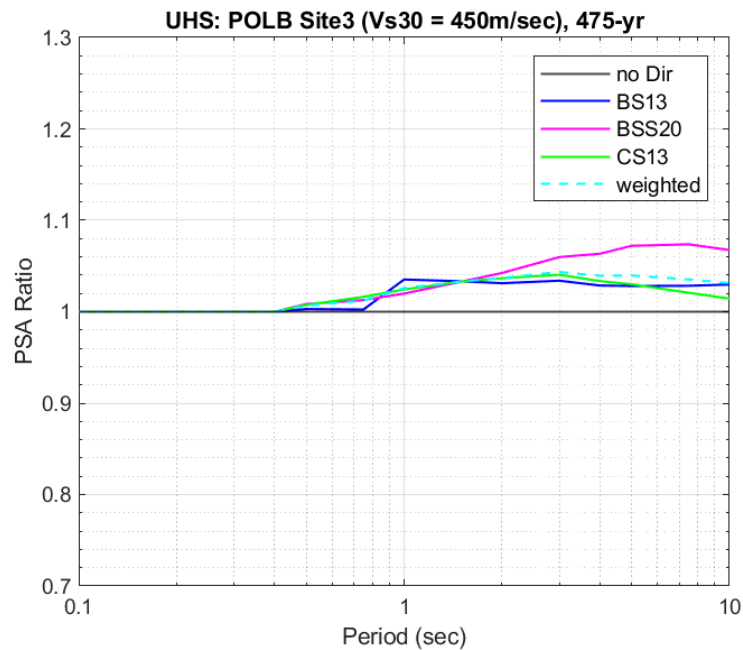


Figure 100. UHS spectral ratio for Site 3 ($V_{s30} = 450\text{ m/sec}$) for the 475-year return period hazard level for the individual and weighted combination directivity models.

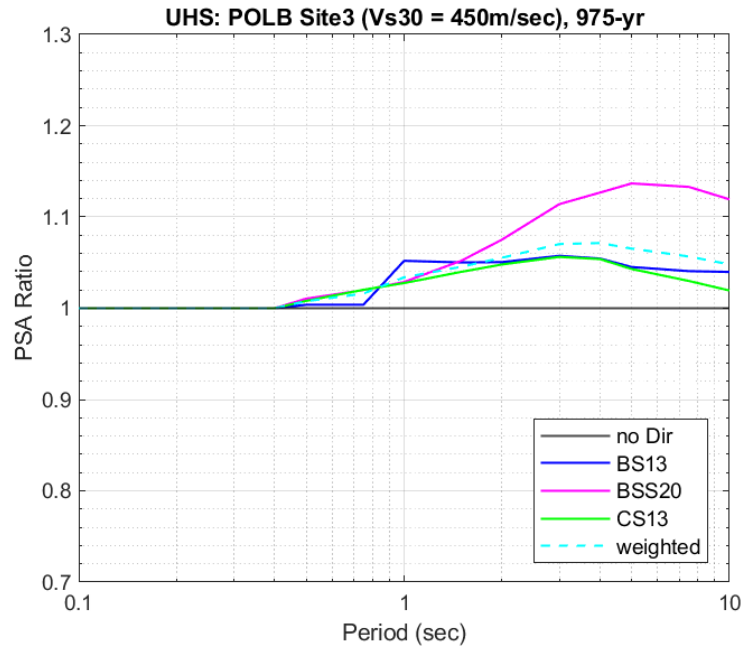


Figure 101. UHS spectral ratio for Site 3 ($V_{s30} = 450$ m/sec) for the 975-year return period hazard level for the individual and weighted combination directivity models.

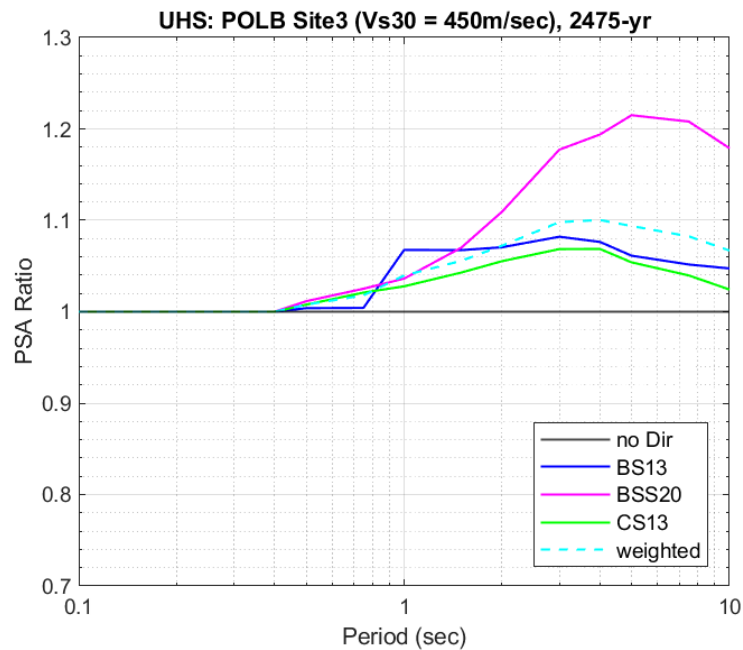


Figure 102. UHS spectral ratio for Site 3 ($V_{s30} = 450$ m/sec) for the 2,475-year return period hazard level for the individual and weighted combination directivity models.

Table 19. Horizontal UHS for Site 3 ($V_{S30} = 450$ m/sec) at the four hazard levels with the inclusion of the combined weighted directivity models.

Period (sec)	72-year Horizontal PSA (g)	475-year Horizontal PSA (g)	975-year Horizontal PSA (g)	2,475-year Horizontal PSA (g)
0.01	0.1552	0.4482	0.6250	0.9064
0.02	0.1562	0.4542	0.6335	0.9182
0.03	0.1665	0.4861	0.6743	0.9718
0.04	0.1844	0.5397	0.7443	1.0639
0.05	0.2042	0.5907	0.8252	1.1754
0.075	0.2609	0.7478	1.0336	1.4941
0.1	0.3114	0.8858	1.2071	1.7205
0.15	0.3639	1.0257	1.4277	2.0098
0.2	0.3719	1.0679	1.5072	2.1614
0.25	0.3598	1.0552	1.5101	2.2119
0.3	0.3399	1.0087	1.4602	2.1597
0.4	0.2898	0.8800	1.2719	1.9158
0.5	0.2506	0.7730	1.1315	1.7390
0.75	0.1750	0.5563	0.8378	1.3218
1	0.1281	0.4206	0.6444	1.0397
1.5	0.0791	0.2659	0.4113	0.6713
2	0.0546	0.1883	0.2931	0.4817
3	0.0324	0.1167	0.1841	0.3073
4	0.0219	0.0817	0.1289	0.2140
5	0.0158	0.0609	0.0953	0.1572
7.5	0.0088	0.0358	0.0542	0.0859
10	0.0055	0.0237	0.0354	0.0549

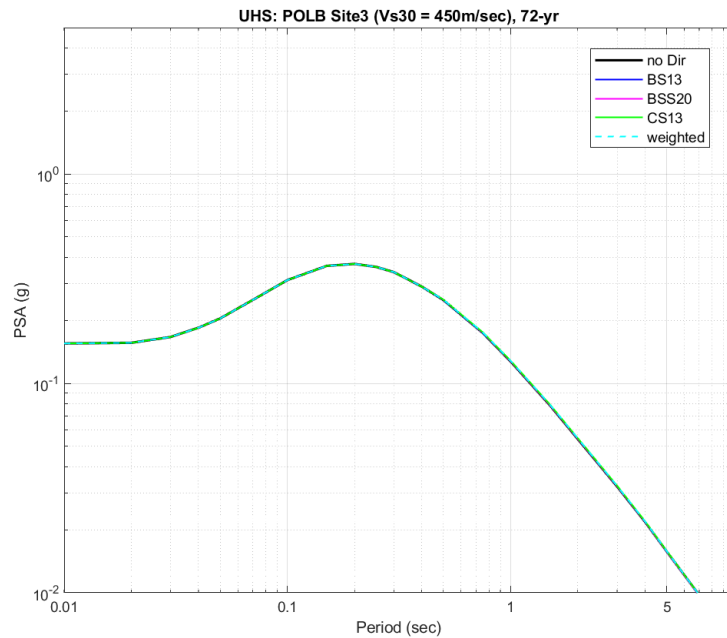


Figure 103. Uniform hazard spectra for Site 3 ($V_{S30} = 450$ m/sec) without directivity (black line) and with the individual and combined weighted (dashed blue line) directivity models for the 72-year return period.

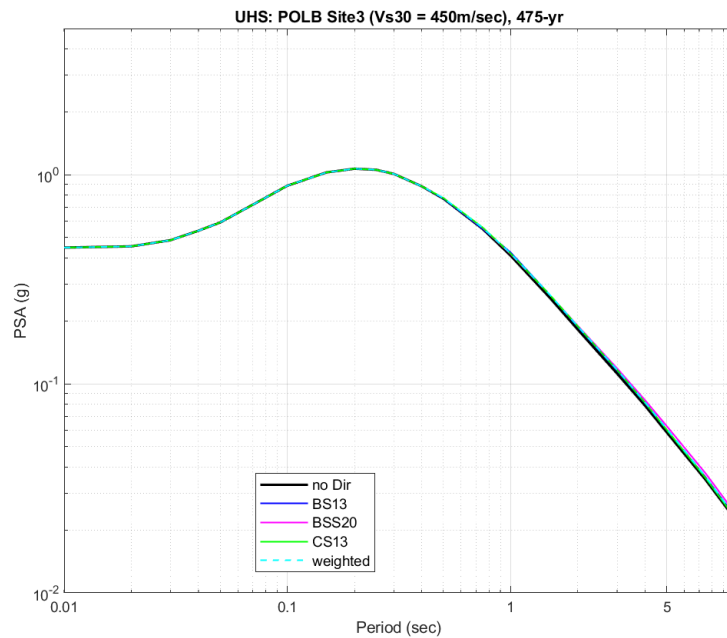


Figure 104. Uniform hazard spectra for Site 3 ($V_{S30} = 450$ m/sec) without directivity (black line) and with the individual and combined weighted (dashed blue line) directivity models for the 475-year return period.

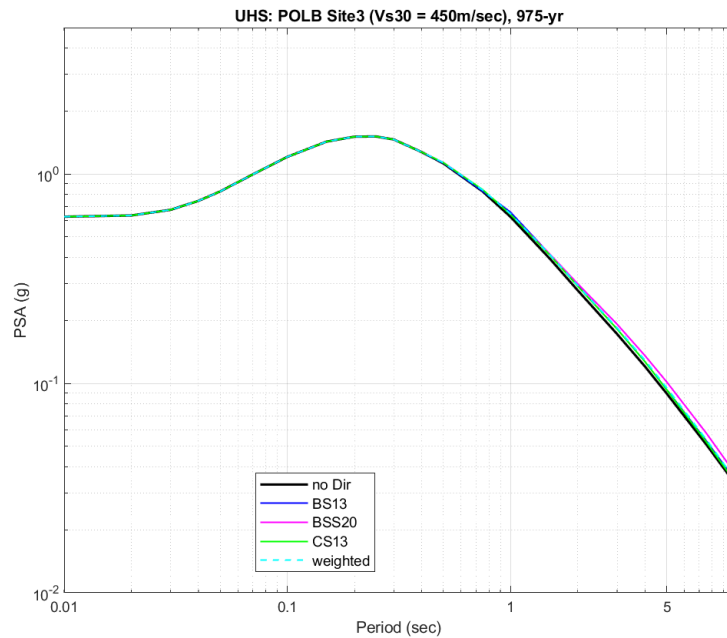


Figure 105. Uniform hazard spectra for Site 3 ($V_{S30} = 450$ m/sec) without directivity (black line) and with the individual and combined weighted (dashed blue line) directivity models for the 975-year return period.

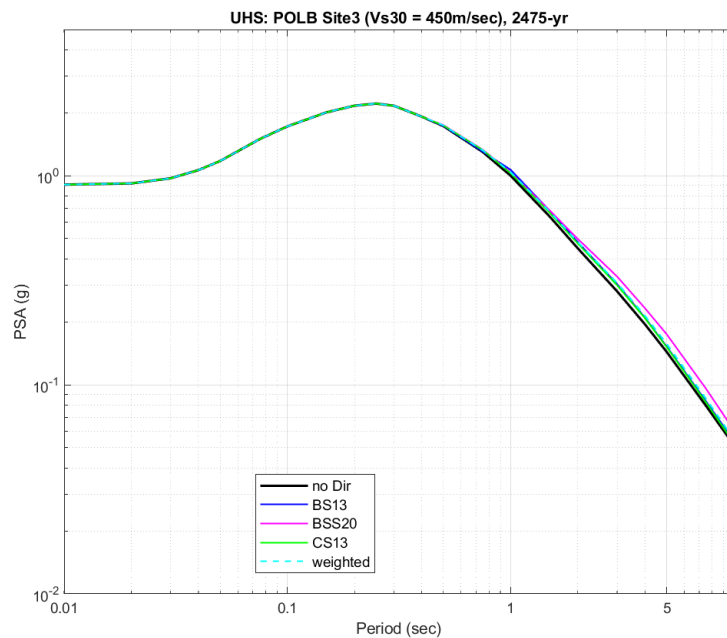


Figure 106. Uniform hazard spectra for Site 3 ($V_{S30} = 450$ m/sec) without directivity (black line) and with the individual and combined weighted (dashed blue line) directivity models for the 2,475-year return period.

Only the Bayless and Somerville (2013) directivity model is defined for the fault normal and fault parallel components of motions including directivity. The other directivity models are defined for the average horizontal component including directivity. Thus, ground motions are computed based on the application of only the Bayless and Somerville (2013) directivity model for the three cases of average horizontal, fault normal and fault parallel components. The resulting UHS for the selected four return period hazard levels are plotted in Figure 107 through 110 and listed in Table 20 through Table 22. The spectral ratio results for are plotted in Figure 111 through 114 for the selected return periods. These results show a small impact from the application of the BS13 directivity model for the 72-yr hazard level. The impact, however, increases with increasing return period hazard level and as well spectral period. For the longer return period hazard levels and longer spectral periods, the fault normal results are increased by up to about 18% relative to the average horizontal component with directivity. For the fault parallel component, the ground motions are observed to approach a reduction of approximately 10% relative to the average horizontal component.

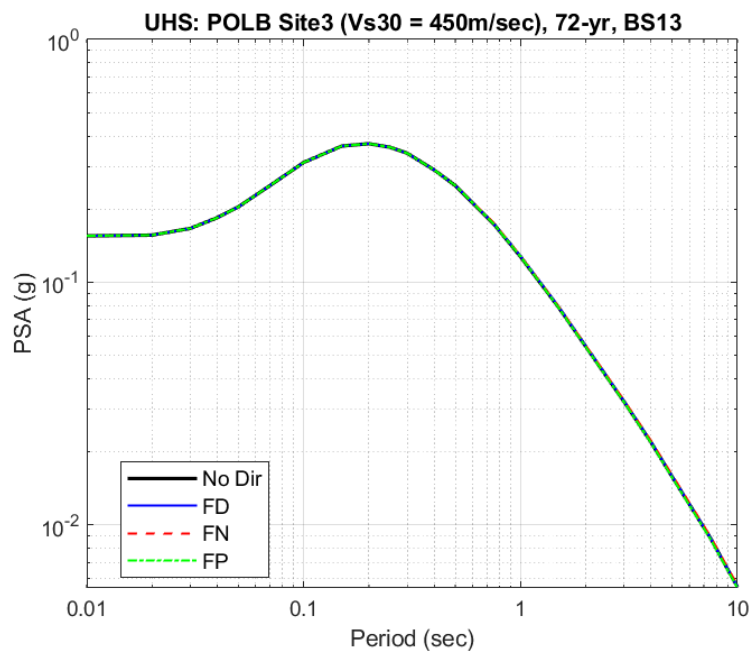


Figure 107. Uniform hazard spectra for Site 3 ($V_{s30} = 450$ m/sec) without directivity (black line) and with the BS13 directivity model for average horizontal (FD), fault normal (FN) and fault parallel (FP) components for the 72-year return period.

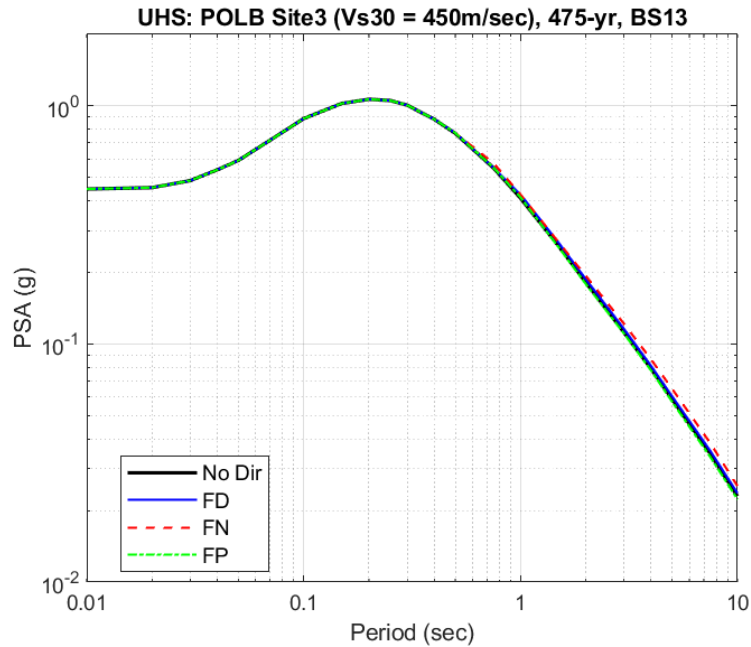


Figure 108. Uniform hazard spectra for Site 3 ($V_{s30} = 450$ m/sec) without directivity (black line) and with the BS13 directivity model for average horizontal (FD), fault normal (FN) and fault parallel (FP) components for the 475-year return period.

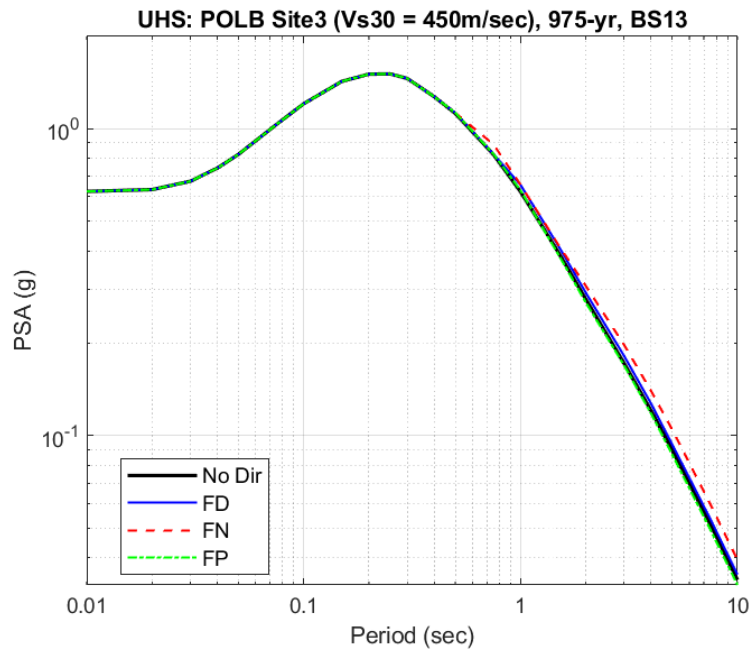


Figure 109. Uniform hazard spectra for Site 3 ($V_{s30} = 450$ m/sec) without directivity (black line) and with the BS13 directivity model for average horizontal (FD), fault normal (FN) and fault parallel (FP) components for the 975-year return period.

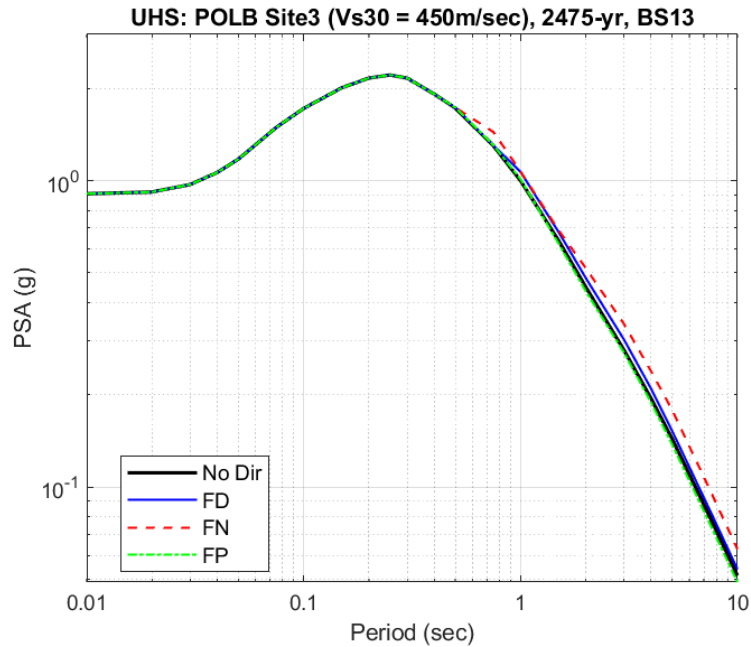


Figure 110. Uniform hazard spectra for Site 3 ($V_{s30} = 450$ m/sec) without directivity (black line) and with the BS13 directivity model for average horizontal (FD), fault normal (FN) and fault parallel (FP) components for the 2,475-year return period.

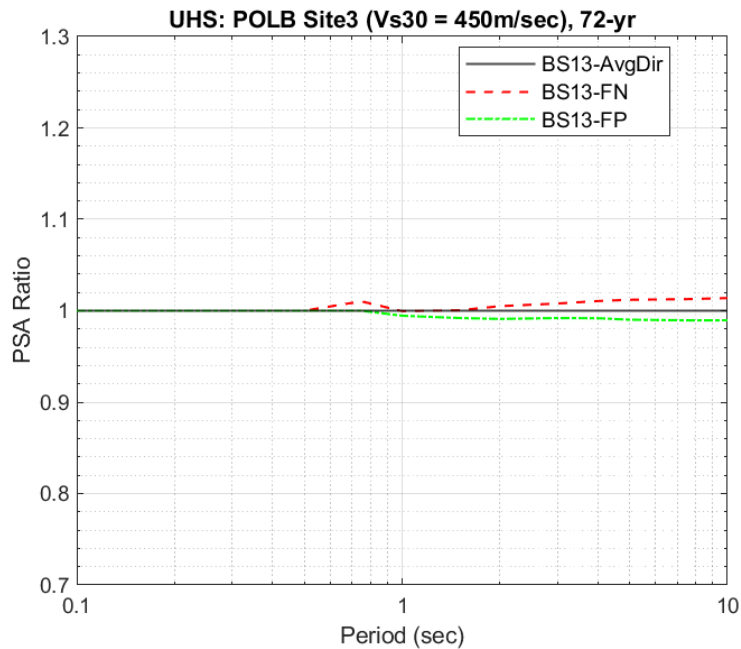


Figure 111. UHS spectral ratio for Site 3 ($V_{s30} = 450$ m/sec) for the 72-year return period hazard level for the individual horizontal components of the BS13 directivity models.

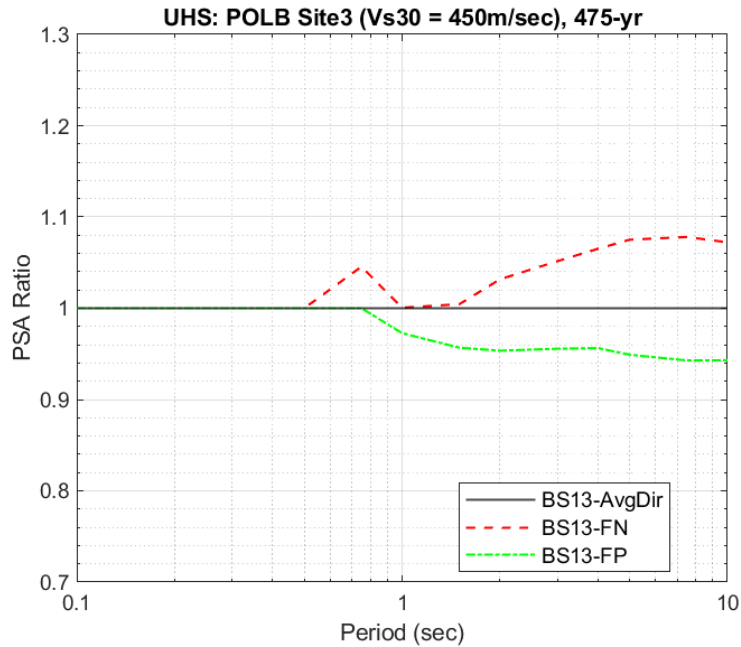


Figure 112. UHS spectral ratio for Site 3 ($V_{s30} = 450\text{ m/sec}$) for the 475-year return period hazard level for the individual horizontal components of the BS13 directivity models.

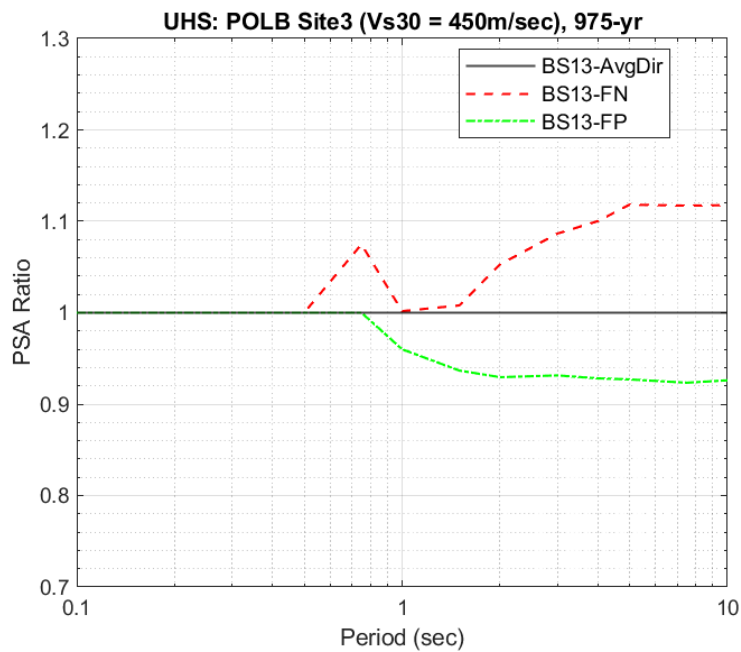


Figure 113. UHS spectral ratio for Site 3 ($V_{s30} = 450\text{ m/sec}$) for the 975-year return period hazard level for the individual horizontal components of the BS13 directivity models.

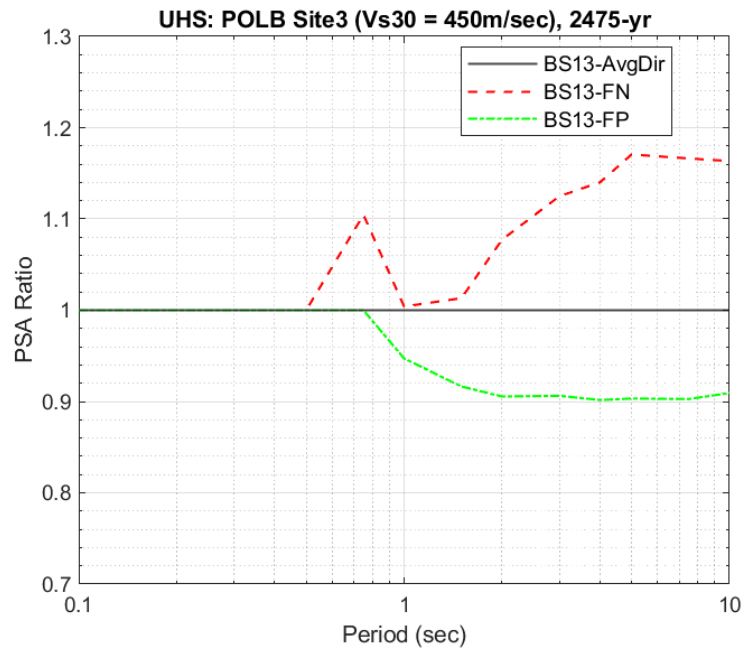


Figure 114. UHS spectral ratio for Site 3 ($V_{s30} = 450$ m/sec) for the 2,475-year return period hazard level for the individual horizontal components of the BS13 directivity models.

Table 20. Horizontal UHS for Site 3 ($V_{S30} = 450$ m/sec) at the four hazard levels with the inclusion of the BS13 directivity models for the average horizontal component.

Period (sec)	72-year Horizontal BS13 (FD) PSA (g)	475-year Horizontal BS13 (FD) PSA (g)	975-year Horizontal BS13 (FD) PSA (g)	2,475-year Horizontal BS13 (FD) PSA (g)
0.01	0.1552	0.4482	0.6250	0.9064
0.02	0.1562	0.4542	0.6335	0.9182
0.03	0.1665	0.4861	0.6743	0.9718
0.04	0.1844	0.5397	0.7443	1.0639
0.05	0.2042	0.5907	0.8252	1.1754
0.075	0.2609	0.7478	1.0336	1.4941
0.1	0.3114	0.8858	1.2071	1.7205
0.15	0.3639	1.0257	1.4277	2.0098
0.2	0.3719	1.0679	1.5072	2.1614
0.25	0.3598	1.0552	1.5101	2.2119
0.3	0.3399	1.0087	1.4602	2.1597
0.4	0.2898	0.8800	1.2719	1.9158
0.5	0.2500	0.7702	1.1272	1.7324
0.75	0.1742	0.5510	0.8277	1.3041
1	0.1281	0.4245	0.6557	1.0676
1.5	0.0790	0.2660	0.4132	0.6787
2	0.0545	0.1872	0.2918	0.4809
3	0.0323	0.1156	0.1818	0.3028
4	0.0219	0.0808	0.1269	0.2093
5	0.0158	0.0603	0.0935	0.1525
7.5	0.0088	0.0355	0.0534	0.0835
10	0.0056	0.0236	0.0352	0.0539

Table 21. Horizontal UHS for Site 3 ($V_{S30} = 450$ m/sec) at the four hazard levels with the inclusion of the BS13 directivity models for the fault normal (FN) component.

Period (sec)	72-year Horizontal BS13 (FN) PSA (g)	475-year Horizontal BS13 (FN) PSA (g)	975-year Horizontal BS13 (FN) PSA (g)	2,475-year Horizontal BS13 (FN) PSA (g)
0.01	0.1552	0.4482	0.6250	0.9064
0.02	0.1562	0.4542	0.6335	0.9182
0.03	0.1665	0.4861	0.6743	0.9718
0.04	0.1844	0.5397	0.7443	1.0639
0.05	0.2042	0.5907	0.8252	1.1754
0.075	0.2609	0.7478	1.0336	1.4941
0.1	0.3114	0.8858	1.2071	1.7205
0.15	0.3639	1.0257	1.4277	2.0098
0.2	0.3719	1.0679	1.5072	2.1614
0.25	0.3598	1.0552	1.5101	2.2119
0.3	0.3399	1.0087	1.4602	2.1597
0.4	0.2898	0.8800	1.2719	1.9158
0.5	0.2500	0.7702	1.1272	1.7324
0.75	0.1760	0.5761	0.8896	1.4404
1	0.1280	0.4247	0.6568	1.0720
1.5	0.0790	0.2672	0.4165	0.6877
2	0.0547	0.1932	0.3072	0.5181
3	0.0326	0.1216	0.1976	0.3406
4	0.0221	0.0861	0.1396	0.2387
5	0.0160	0.0648	0.1046	0.1786
7.5	0.0090	0.0383	0.0597	0.0974
10	0.0056	0.0253	0.0393	0.0628

Table 22. Horizontal UHS for Site 3 ($V_{S30} = 450$ m/sec) at the four hazard levels with the inclusion of the BS13 directivity models for the fault parallel (FP) component.

Period (sec)	72-year Horizontal BS13 (FP) PSA (g)	475-year Horizontal BS13 (FP) PSA (g)	975-year Horizontal BS13 (FP) PSA (g)	2,475-year Horizontal BS13 (FP) PSA (g)
0.01	0.1552	0.4482	0.6250	0.9064
0.02	0.1562	0.4542	0.6335	0.9182
0.03	0.1665	0.4861	0.6743	0.9718
0.04	0.1844	0.5397	0.7443	1.0639
0.05	0.2042	0.5907	0.8252	1.1754
0.075	0.2609	0.7478	1.0336	1.4941
0.1	0.3114	0.8858	1.2071	1.7205
0.15	0.3639	1.0257	1.4277	2.0098
0.2	0.3719	1.0679	1.5072	2.1614
0.25	0.3598	1.0552	1.5101	2.2119
0.3	0.3399	1.0087	1.4602	2.1597
0.4	0.2898	0.8800	1.2719	1.9158
0.5	0.2500	0.7702	1.1272	1.7324
0.75	0.1742	0.5510	0.8277	1.3041
1	0.1274	0.4129	0.6295	1.0112
1.5	0.0783	0.2545	0.3870	0.6220
2	0.0540	0.1785	0.2712	0.4355
3	0.0321	0.1105	0.1694	0.2744
4	0.0217	0.0773	0.1178	0.1887
5	0.0157	0.0572	0.0867	0.1378
7.5	0.0088	0.0335	0.0493	0.0754
10	0.0055	0.0223	0.0326	0.0491

4.4 Site 5 Results

4.4.1 Site 5 Results without Directivity, $V_{S30} = 450$ m/sec

The mean hazard curves including the Wilmington fault for Site 5 are shown in Figures 115 through 118 for PGA and spectral periods of 0.2, 1, and 3 sec. For the longer spectral periods (i.e., 1 and 3 sec), these plots show the horizontal component without the inclusion of the directivity models. In these plots, individual hazard curves from the scenario fault ruptures from the UCERF3 faults, gridded sources, the Wilmington fault as well as the combined total hazard are presented. Hazard levels corresponding to the 475 and 2,475-year return periods are also plotted in the figures. For the short to intermediate spectral periods, the hazard is equally

controlled by the UCERF3 grid and fault sources for hazard levels of about 100 to 200 years. For shorter return periods and the intermediate to short periods, the hazard is controlled by the gridded source. For longer return periods and as well longer spectral periods, the hazard is controlled by the UCERF3 fault sources. For all cases, the contribution from the Wilmington fault is less than from the other UCERF3 sources.

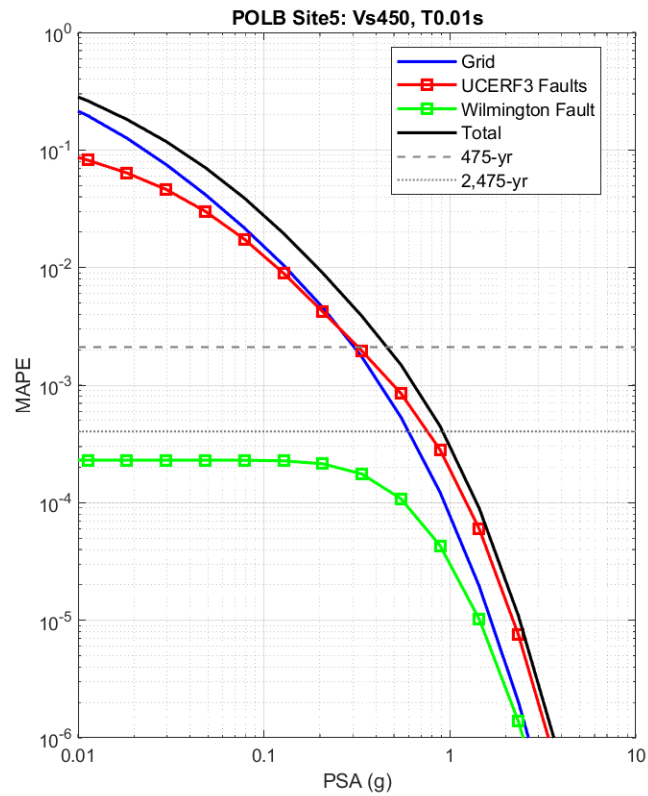


Figure 115. Mean horizontal component hazard curves from the UCERF3 gridded and fault sources, Wilmington fault, and total mean hazard for PGA for Site 5 for $V_{s30} = 450$ m/sec without directivity. MAPE refers to mean annual probability of exceedance.

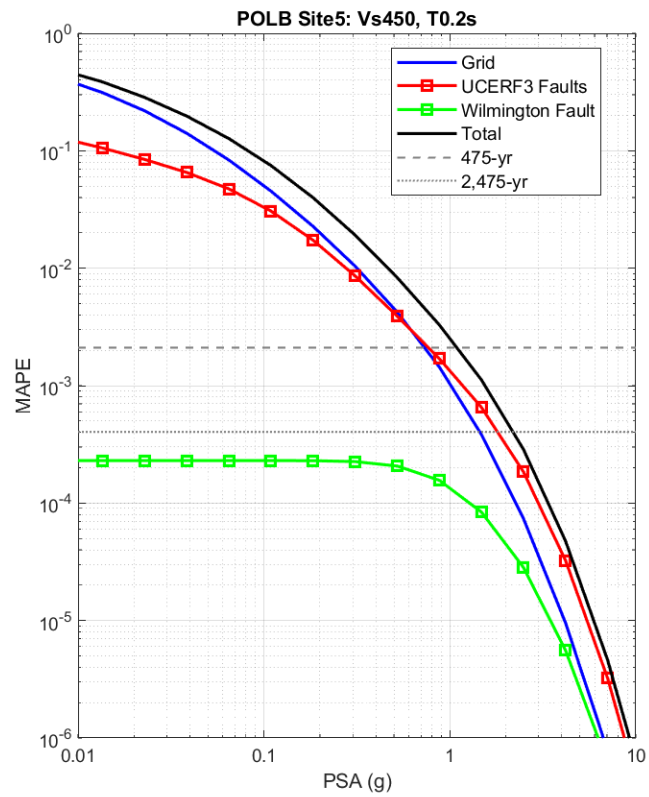


Figure 116. Mean horizontal component hazard curves from the UCERF3 gridded and fault sources, Wilmington fault, and total mean hazard for $T=0.2$ sec for Site 5 for $V_{S30} = 450$ m/sec without directivity. MAPE refers to mean annual probability of exceedance.

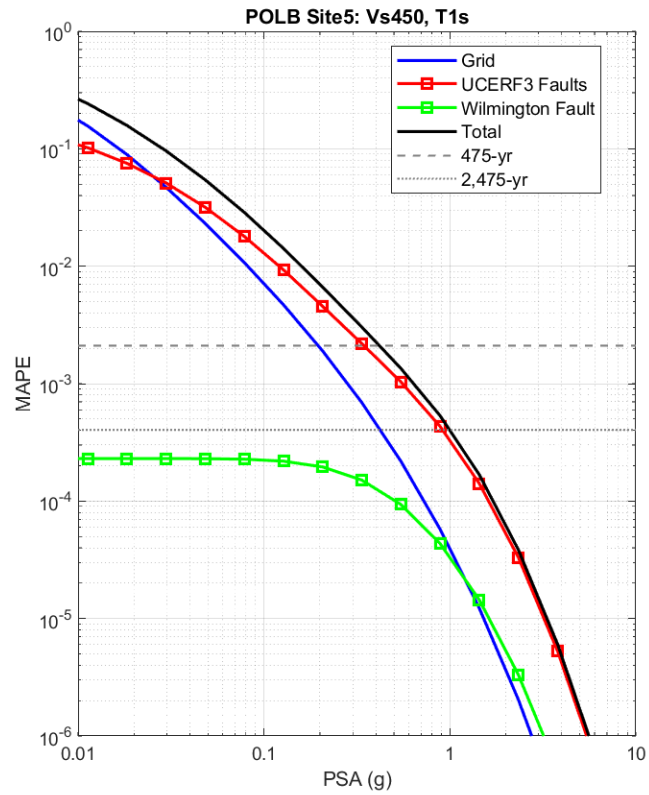


Figure 117. Mean horizontal component hazard curves from the UCERF3 gridded and fault sources, Wilmington fault, and total mean hazard for $T=1.0$ sec for Site 5 for $V_{s30} = 450$ m/sec without directivity. MAPE refers to mean annual probability of exceedance.

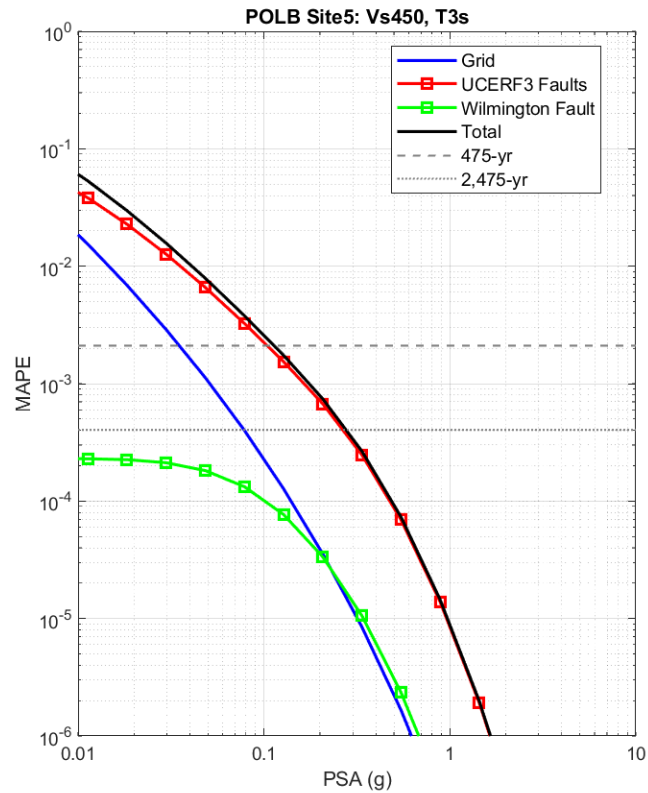


Figure 118. Mean horizontal component hazard curves from the UCERF3 gridded and fault sources, Wilmington fault, and total mean hazard for $T=3.0$ sec for Site 5 for $V_{s30} = 450$ m/sec without directivity. MAPE refers to mean annual probability of exceedance.

To further illustrate the contribution from the parent fault systems from the UCERF3 database and the Wilmington fault, the ranked top 15 contributing parent fault hazard curves at the 2,475-year hazard level are plotted along with the total combined hazard curve from just fault sources including the Wilmington fault. These results are plotted in Figures 119 through 122 for the same previous four spectral periods. Note that given the change in the relative ranking order the line and symbol type for a given parent fault varies from one plot to another. The largest contributing parent fault system to the total fault hazard is the Palos Verdes fault which is an expected result given the close distance to the site and the assigned slip rate for this fault relative to the other faults in the area. The Wilmington fault has a similar contribution to the Compton fault for the intermediate and short periods and a lesser contribution at the longer spectral periods.

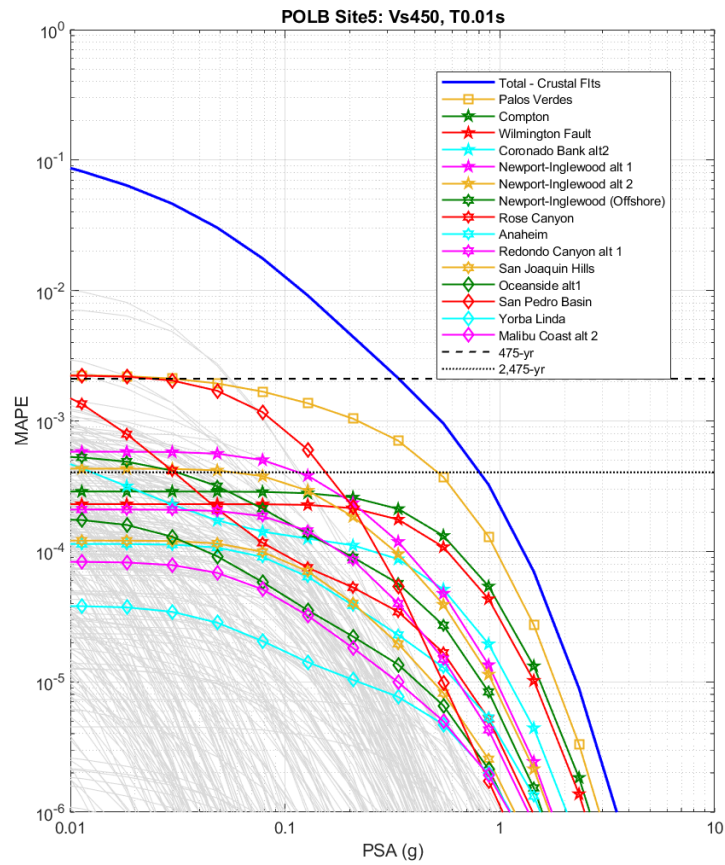


Figure 119. Mean horizontal component hazard curves from the Wilmington and UCERF3 parent fault sources at PGA for Site 5 for $V_{s30} = 450$ m/sec without directivity. The colored individual-fault hazard curves show the top contributing parent faults to the total hazard from crustal faults. MAPE refers to mean annual probability of exceedance.

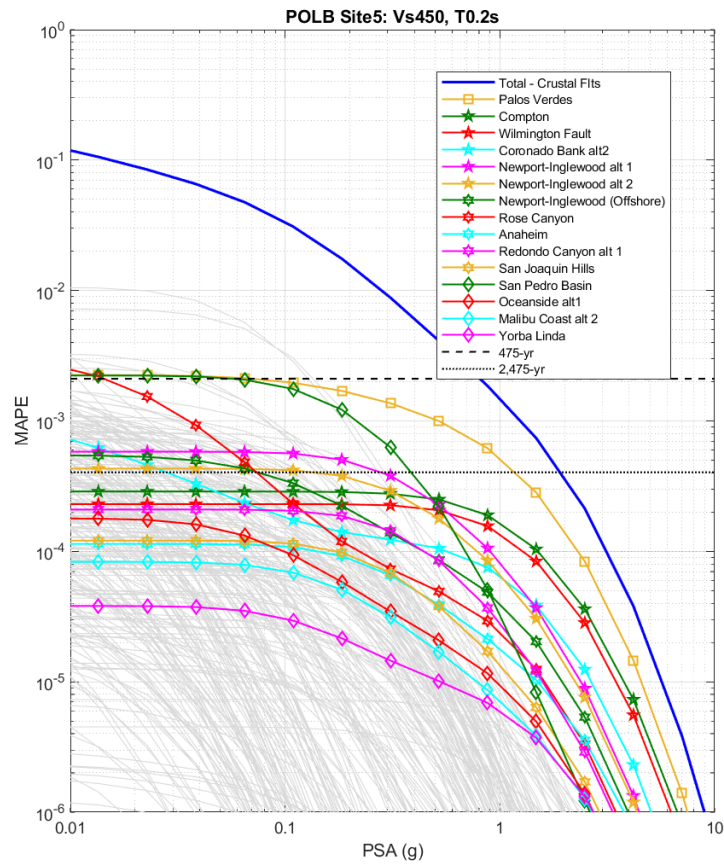


Figure 120. Mean horizontal component hazard curves from the Wilmington and UCERF3 parent fault sources at $T=0.2$ sec for Site 5 for $V_{s30} = 450$ m/sec without directivity. The colored individual-fault hazard curves show the top contributing parent faults to the total hazard from crustal faults. MAPE refers to mean annual probability of exceedance.

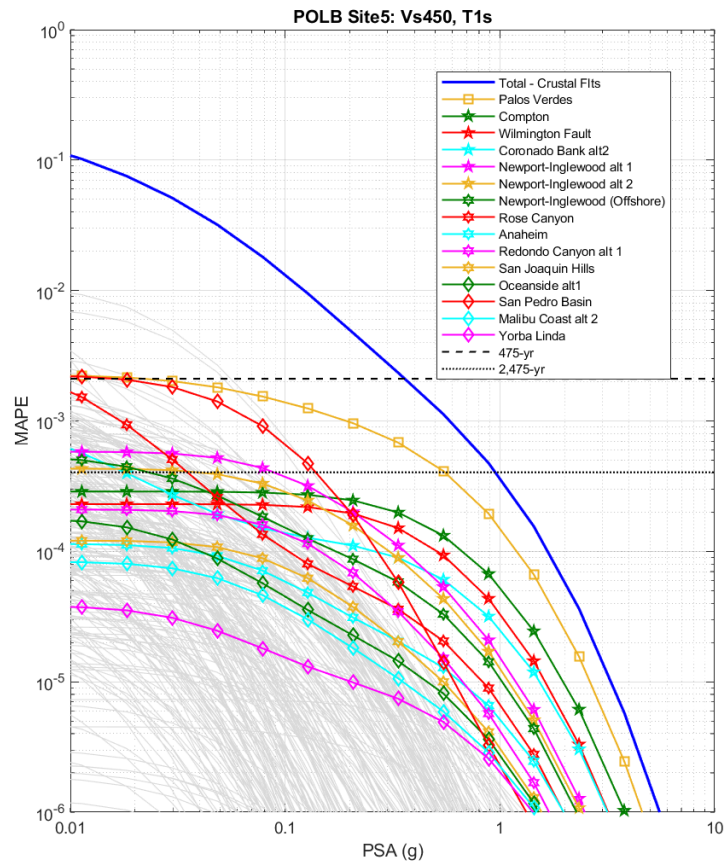


Figure 121. Mean horizontal component hazard curves from the Wilmington and UCERF3 parent fault sources at $T=1.0$ sec for Site 5 for $V_{s30} = 450$ m/sec without directivity. The colored individual-fault hazard curves show the top contributing parent faults to the total hazard from crustal faults. MAPE refers to mean annual probability of exceedance.

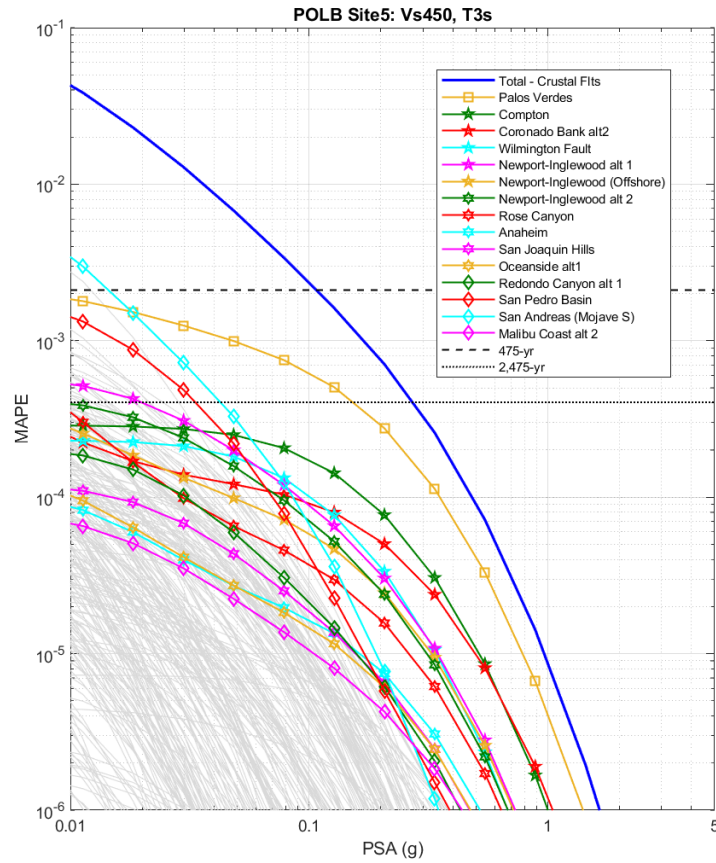


Figure 122. Mean horizontal component hazard curves from the Wilmington and UCERF3 parent fault sources at $T=3.0$ sec for Site 5 for $V_{s30} = 450$ m/sec without directivity. The colored individual-fault hazard curves show the top contributing parent faults to the total hazard from crustal faults. MAPE refers to mean annual probability of exceedance.

Given the hazard curves for the full suite of spectral periods, the computed uniform hazard spectra (UHS) for the selected 72, 475, 975 and 2,475-year return period hazard levels are plotted in Figure 123 for the average horizontal component without the inclusion of the directivity models. These horizontal UHS values for the return period hazard levels at all spectral periods are given in Table 23.

Table 23. Horizontal UHS for Site 5 ($V_{S30} = 450$ m/sec) at the suite of hazard levels without the inclusion of the directivity models.

Period (sec)	72-year Horizontal PSA (g)	475-year Horizontal PSA (g)	975-year Horizontal PSA (g)	2,475-year Horizontal PSA (g)
0.01	0.1583	0.4578	0.6342	0.9132
0.02	0.1595	0.4641	0.6429	0.9249
0.03	0.1701	0.4969	0.6847	0.9794
0.04	0.1884	0.5511	0.7567	1.0733
0.05	0.2086	0.6025	0.8400	1.1869
0.075	0.2664	0.7639	1.0501	1.5086
0.1	0.3180	0.9026	1.2276	1.7381
0.15	0.3712	1.0453	1.4523	2.0278
0.2	0.3794	1.0893	1.5283	2.1810
0.25	0.3669	1.0765	1.5309	2.2311
0.3	0.3465	1.0293	1.4830	2.1788
0.4	0.2957	0.8982	1.2924	1.9301
0.5	0.2547	0.7848	1.1394	1.7349
0.75	0.1774	0.5606	0.8348	1.2980
1	0.1295	0.4177	0.6288	0.9950
1.5	0.0798	0.2618	0.3961	0.6313
2	0.0550	0.1845	0.2794	0.4455
3	0.0326	0.1133	0.1723	0.2760
4	0.0221	0.0794	0.1203	0.1914
5	0.0160	0.0591	0.0894	0.1420
7.5	0.0089	0.0348	0.0514	0.0789
10	0.0056	0.0231	0.0338	0.0513

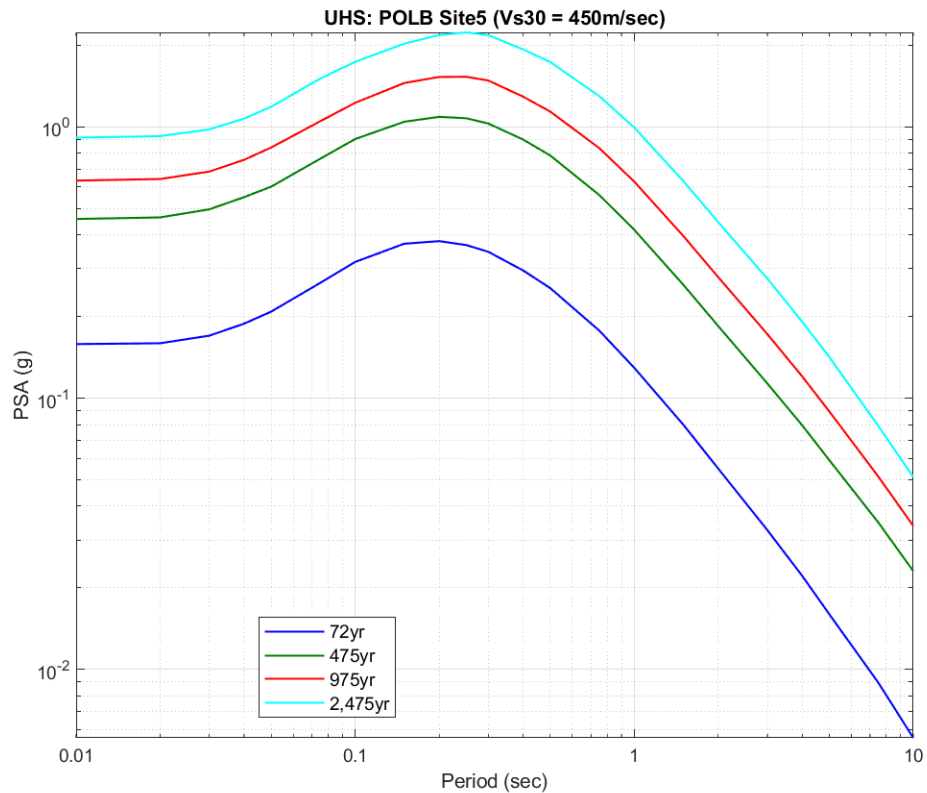


Figure 123. Uniform hazard spectra for Site 5 ($V_{s30} = 450$ m/sec) without the inclusion of the directivity model.

The mean magnitude, distance, and epsilon values for the horizontal component without the directivity models are plotted in Figures 124 to 126 for the selected four hazard levels. These results are plotted as a function of spectral period. In general, the magnitude increases with the increasing return period and spectral periods. For the mean distance values, the distances also decrease as a function of increasing return period but are larger for the longer spectral period given the greater distance to the larger magnitude faults in the region (e.g., San Andreas fault). Finally, the mean epsilon values increase as a function of increasing return periods with the results for the 2,475-year greater than approximately 1 over most of the spectral period range. The mean magnitude, distance, and epsilon values are listed in Tables 24 through 26 for the four hazard levels.

Table 24. Mean magnitude for the four hazard levels for Site 5 ($V_{S30} = 450$ m/sec) without the inclusion of the directivity models.

Period (sec)	72-year Magnitude	475-year Magnitude	975-year Magnitude	2,475-year Magnitude
0.01	6.37	6.60	6.70	6.80
0.02	6.36	6.60	6.70	6.81
0.03	6.36	6.60	6.69	6.79
0.04	6.35	6.58	6.67	6.76
0.05	6.33	6.56	6.66	6.73
0.075	6.30	6.51	6.60	6.69
0.1	6.28	6.50	6.58	6.66
0.15	6.30	6.54	6.64	6.72
0.2	6.35	6.59	6.71	6.79
0.25	6.39	6.65	6.77	6.86
0.3	6.44	6.69	6.82	6.91
0.4	6.52	6.79	6.88	6.98
0.5	6.58	6.84	6.93	7.02
0.75	6.69	6.94	7.02	7.09
1	6.77	7.00	7.07	7.14
1.5	6.90	7.12	7.16	7.21
2	6.98	7.19	7.22	7.25
3	7.11	7.28	7.30	7.31
4	7.18	7.36	7.36	7.37
5	7.23	7.41	7.41	7.41
7.5	7.32	7.53	7.54	7.54
10	7.35	7.59	7.60	7.60

Table 25. Mean distance for the four hazard levels for Site 5 ($V_{S30} = 450$ m/sec) without inclusion of the directivity models.

Period (sec)	72-year Distance (km)	475-year Distance (km)	975-year Distance (km)	2,475-year Distance (km)
0.01	25.98	10.09	7.47	5.76
0.02	25.81	9.94	7.41	5.74
0.03	25.68	9.83	7.58	5.89
0.04	25.33	9.52	7.69	6.10
0.05	24.99	10.20	7.70	6.33
0.075	25.32	10.85	8.40	6.55
0.1	24.86	10.51	8.65	6.94
0.15	25.35	11.01	8.15	6.87
0.2	26.14	11.24	8.10	6.62
0.25	27.21	11.47	8.09	6.46
0.3	28.35	11.75	8.05	6.45
0.4	30.89	12.03	8.95	6.58
0.5	33.89	13.61	9.65	6.65
0.75	38.53	15.03	10.17	6.96
1	40.52	16.82	10.89	7.05
1.5	46.59	20.01	12.93	8.08
2	50.87	21.90	14.53	9.10
3	56.53	25.16	16.73	10.25
4	60.30	27.60	18.74	11.73
5	62.65	31.48	22.11	14.18
7.5	70.82	41.77	34.13	26.38
10	76.70	48.34	41.87	35.30

Table 26. Mean epsilon for the four hazard levels for Site 5 ($V_{S30} = 450$ m/sec) without inclusion of the directivity models.

Period (sec)	72-year Epsilon	475-year Epsilon	975-year Epsilon	2,475-year Epsilon
0.01	0.06	0.52	0.79	1.20
0.02	0.06	0.51	0.79	1.21
0.03	0.08	0.54	0.81	1.21
0.04	0.11	0.57	0.84	1.22
0.05	0.15	0.61	0.88	1.24
0.075	0.19	0.69	0.95	1.33
0.1	0.23	0.74	0.99	1.33
0.15	0.19	0.70	0.97	1.30
0.2	0.17	0.63	0.88	1.23
0.25	0.16	0.57	0.82	1.16
0.3	0.18	0.55	0.79	1.13
0.4	0.19	0.52	0.75	1.10
0.5	0.21	0.51	0.72	1.08
0.75	0.24	0.49	0.70	1.06
1	0.23	0.46	0.66	1.03
1.5	0.21	0.45	0.64	1.00
2	0.16	0.44	0.64	1.00
3	0.08	0.41	0.62	0.97
4	-0.02	0.41	0.62	0.98
5	-0.08	0.41	0.64	0.99
7.5	-0.19	0.48	0.76	1.12
10	-0.30	0.46	0.78	1.16

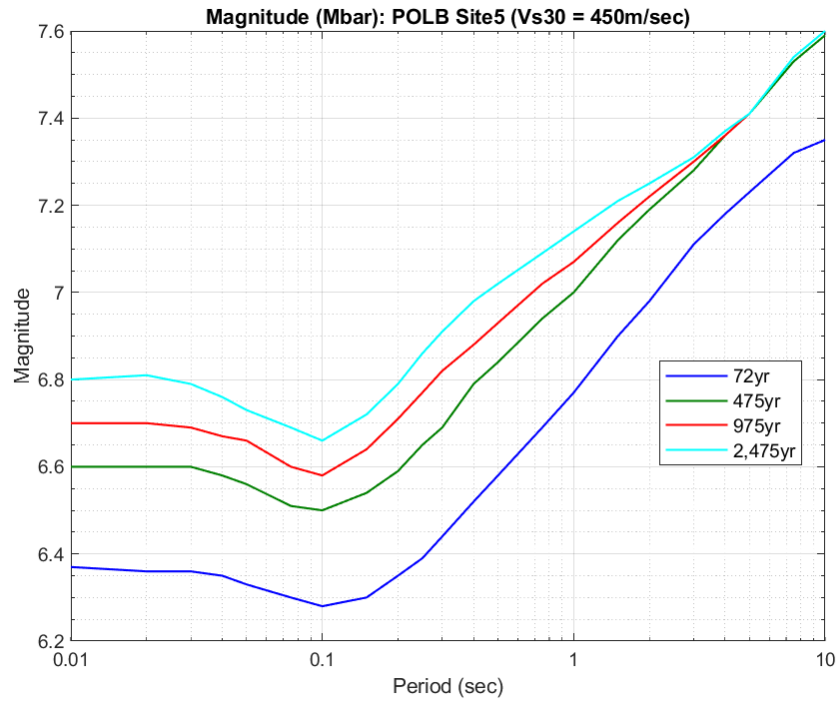


Figure 124. Horizontal mean magnitude for Site 5 ($V_{s30} = 450\text{ m/sec}$) without the inclusion of the directivity models.

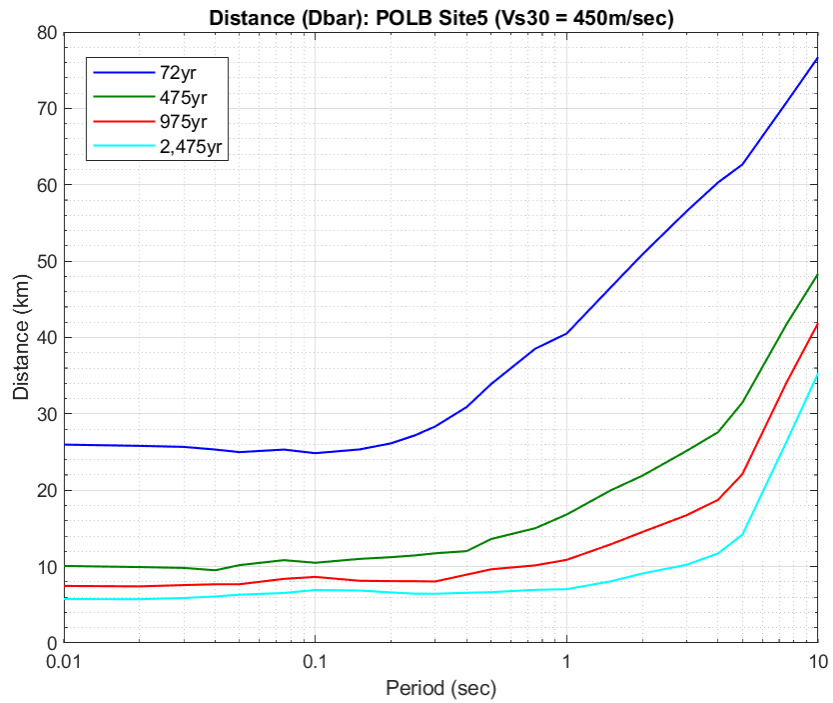


Figure 125. Horizontal mean distance for Site 5 ($V_{s30} = 450\text{ m/sec}$) without the inclusion of the directivity models.

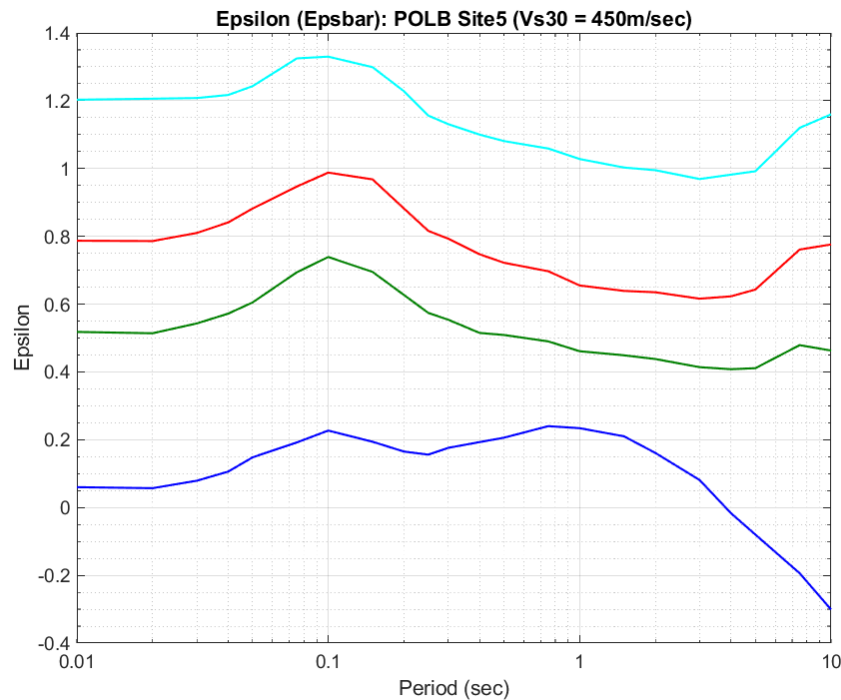


Figure 126. Horizontal mean epsilon for Site 5 ($V_{s30} = 450$ m/sec) without the inclusion of the directivity models.

The binned magnitude and distance contributions to the 72-year hazard level are shown in Figures 127 to 130 for Site 5 ($V_{s30} = 450$ m/sec) for PGA and spectral periods of 0.2, 1.0, and 3.0 sec. Similar plots are shown in Figures 131 to 134 for the 475-year hazard level, Figures 135 to 138 for the 975-year hazard level, and Figures 139 to 142 for the 2,475-year hazard level.

At the shortest return period level of 72 years, the hazard is being contributed to from small to moderate magnitude events over a broad distance of less than about 100 km. At the longer spectral periods, a relative increase in the contribution to the total hazard is observed for the larger magnitude (i.e., greater than 7.0) in the distance bin of 50 – 100 km. This corresponds to the contribution from the San Andreas and San Jacinto faults with their relatively higher slip rates. At the longer return period hazard levels, the relative increased contribution of the local faults to the total hazard is observed in the deaggregation plots with the majority of the contribution from sources with distance less than about 50 km. Based on this increased contribution from these local faults, the relative contribution from the San Andreas fault is decreased even at the longer spectral periods.

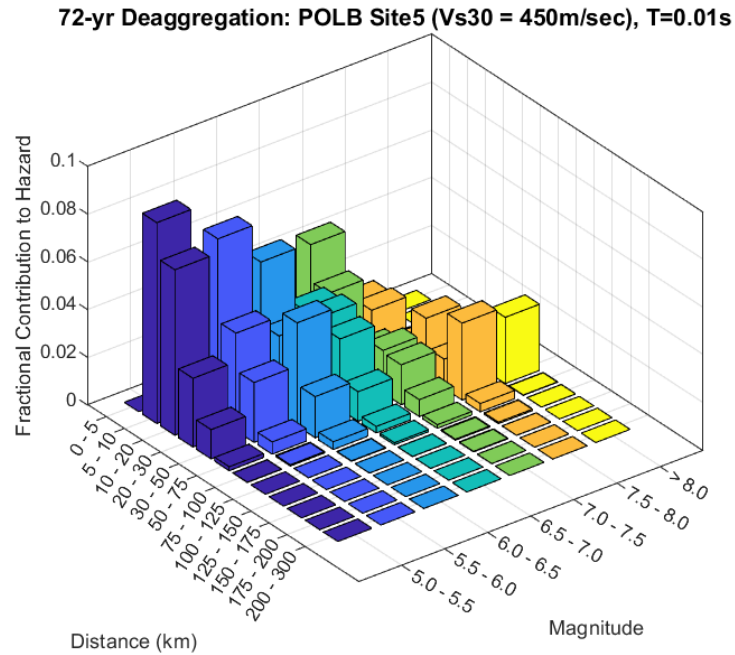


Figure 127. Magnitude-distance contribution for the 72-year hazard level for PGA for Site 5 ($V_{s30} = 450$ m/sec).

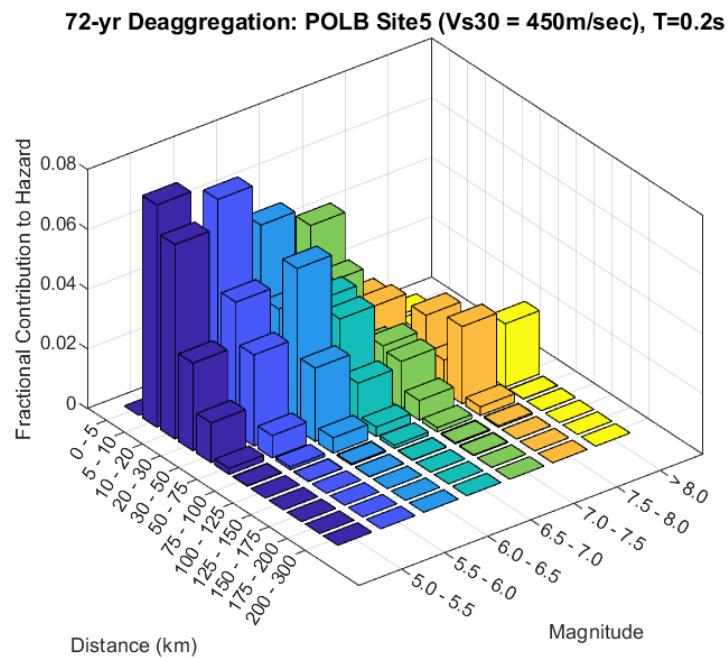


Figure 128. Magnitude-distance contribution for the 72-year hazard level for $T = 0.2$ sec for Site 5 ($V_{s30} = 450$ m/sec).

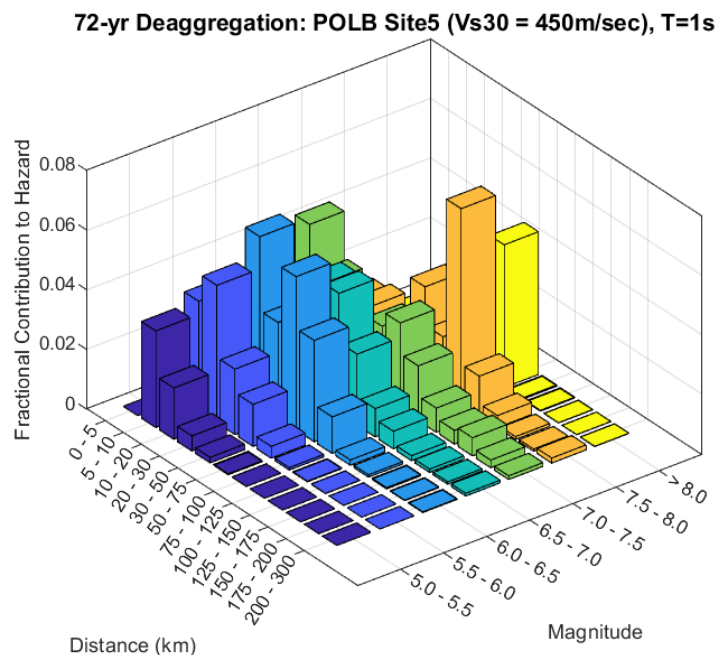


Figure 129. Magnitude-distance contribution for the 72-year hazard level for T = 1.0 sec for Site 5 ($V_{s30} = 450$ m/sec).

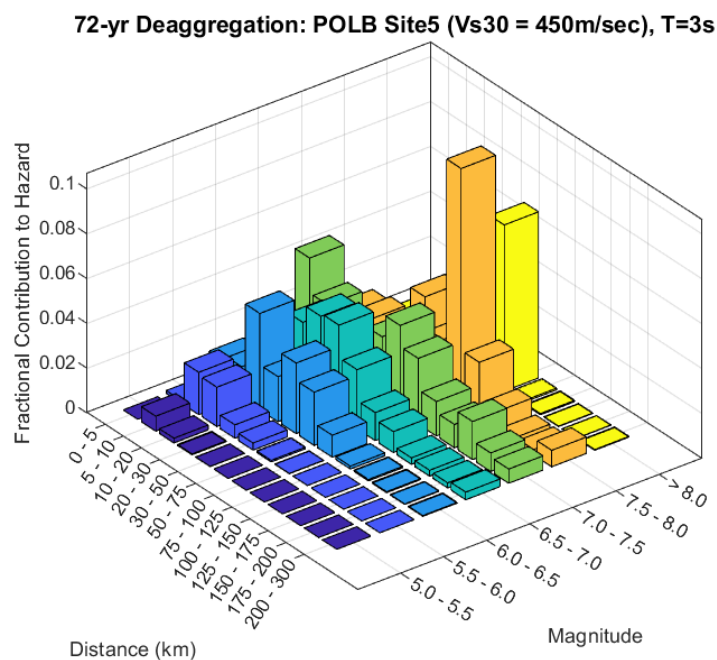


Figure 130. Magnitude-distance contribution for the 72-year hazard level for T = 3.0 sec for Site 5 ($V_{s30} = 450$ m/sec).

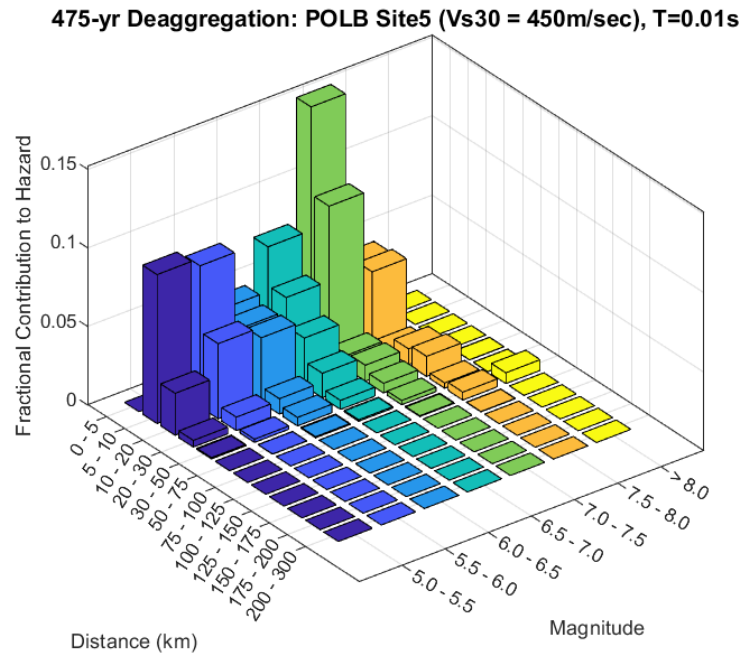


Figure 131. Magnitude-distance contribution for the 475-year hazard level for PGA for Site 5 ($V_{s30} = 450$ m/sec).

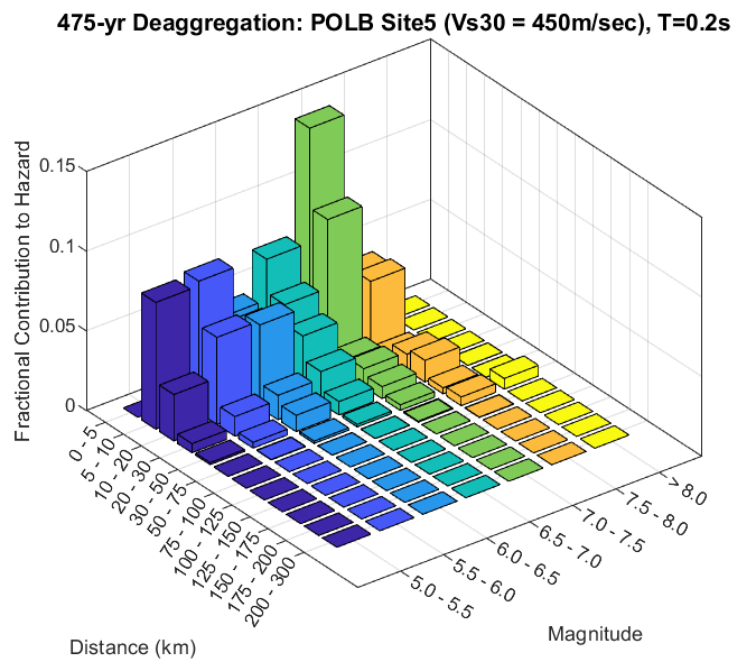


Figure 132. Magnitude-distance contribution for the 475-year hazard level for $T = 0.2$ sec for Site 5 ($V_{s30} = 450$ m/sec).

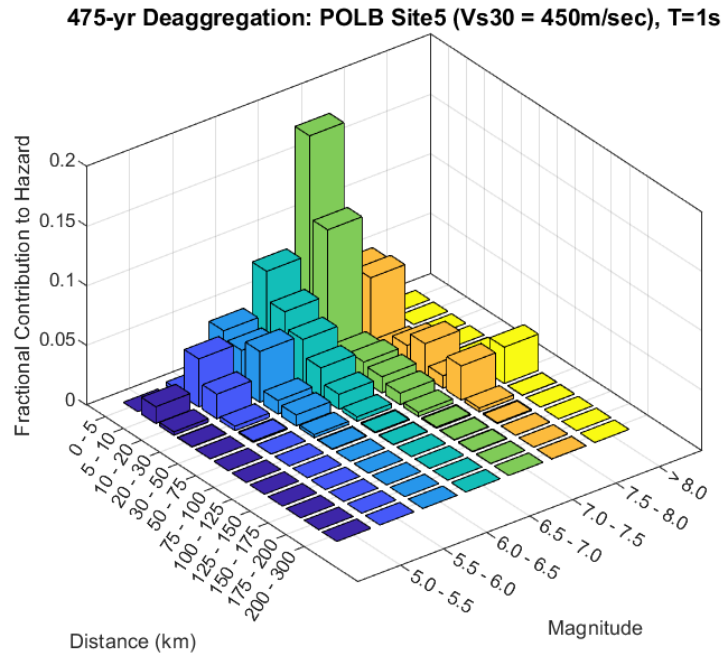


Figure 133. Magnitude-distance contribution for the 475-year hazard level for T = 1.0 sec for Site 5 ($V_{s30} = 450$ m/sec).

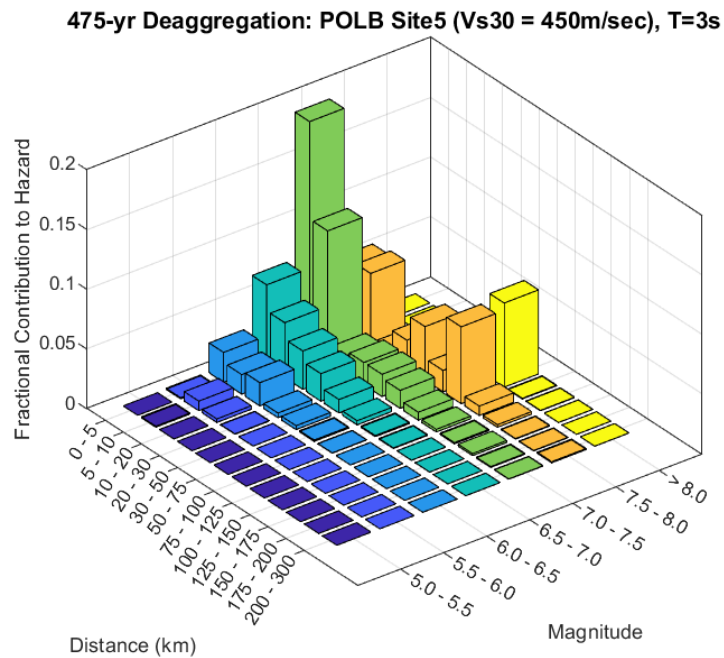


Figure 134. Magnitude-distance contribution for the 475-year hazard level for T = 3.0 sec for Site 5 ($V_{s30} = 450$ m/sec).

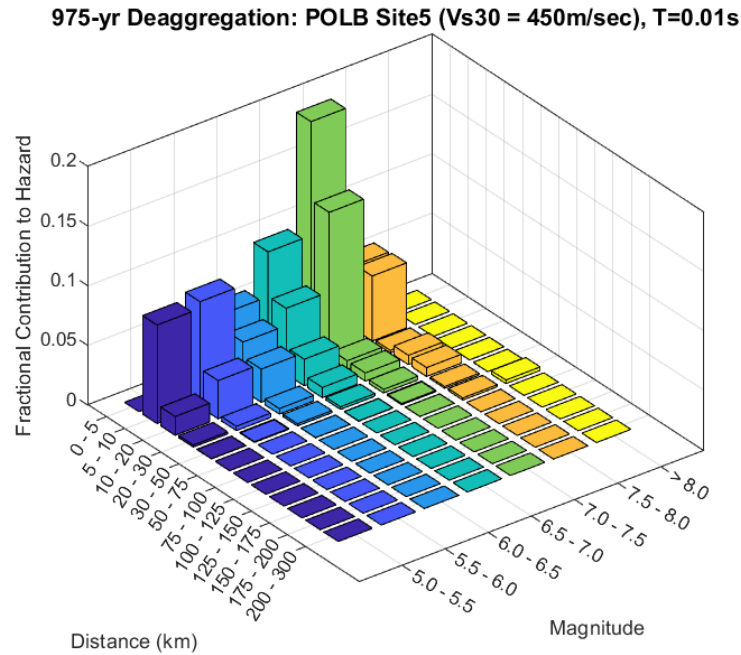


Figure 135. Magnitude-distance contribution for the 975-year hazard level for PGA for Site 5 ($V_{s30} = 450\text{ m/sec}$).

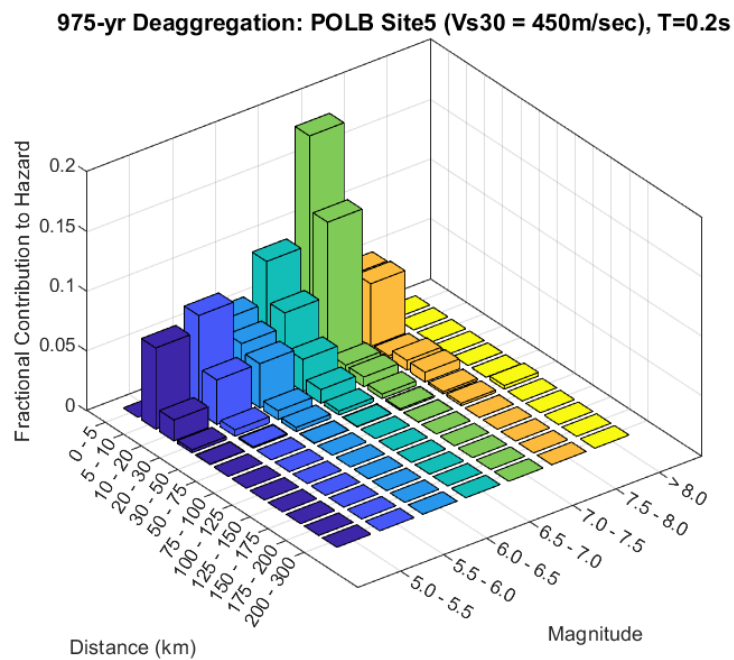


Figure 136. Magnitude-distance contribution for the 975-year hazard level for $T = 0.2\text{ sec}$ for Site 5 ($V_{s30} = 450\text{ m/sec}$).

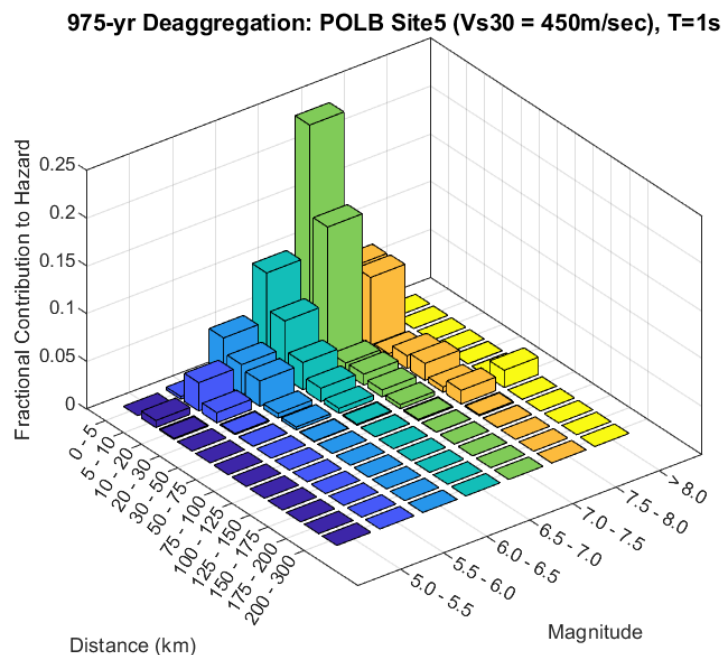


Figure 137. Magnitude-distance contribution for the 975-year hazard level for T = 1.0 sec for Site 5 ($V_{s30} = 450$ m/sec).

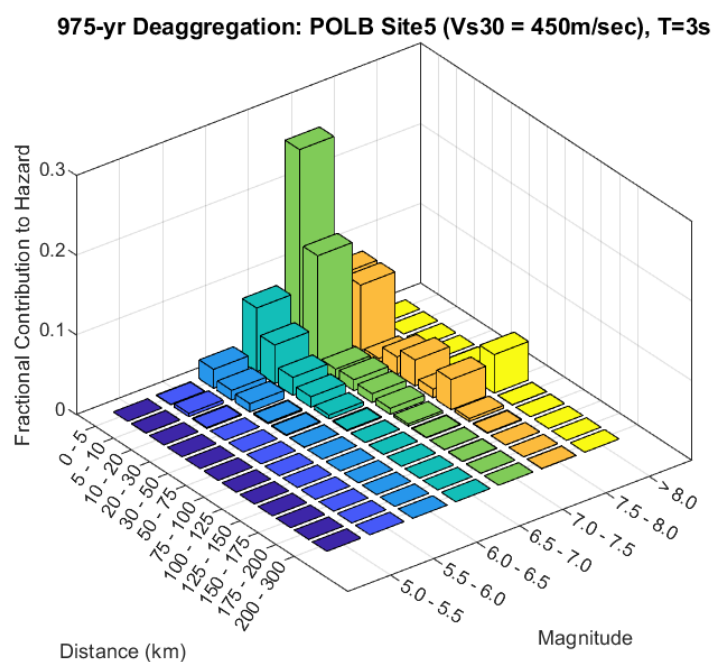


Figure 138. Magnitude-distance contribution for the 975-year hazard level for T = 3.0 sec for Site 5 ($V_{s30} = 450$ m/sec).

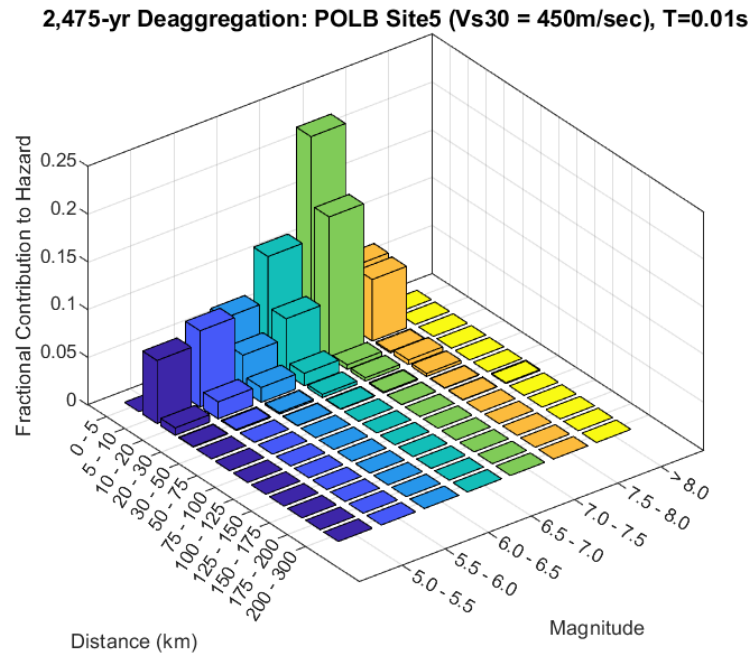


Figure 139. Magnitude-distance contribution for the 2,475-year hazard level for PGA for Site 5 ($V_{s30} = 450\text{ m/sec}$).

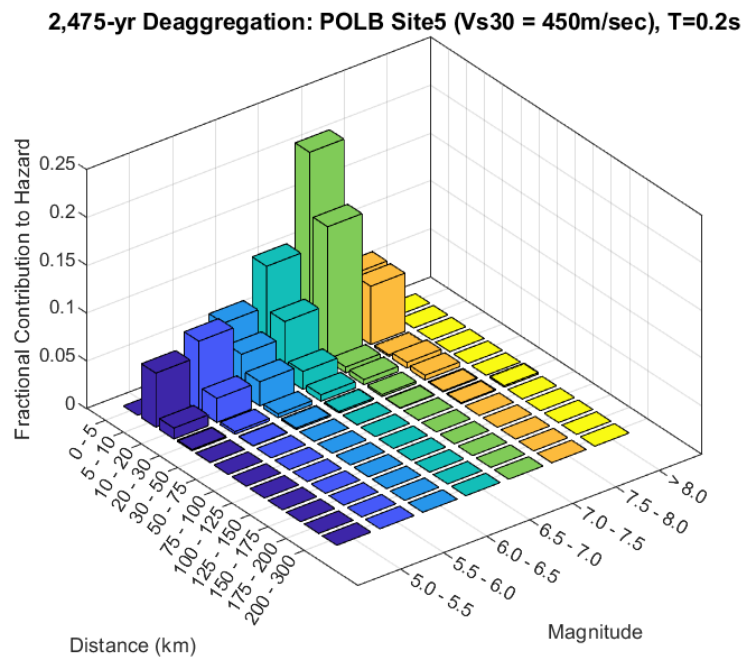


Figure 140. Magnitude-distance contribution for the 2,475-year hazard level for $T = 0.2\text{ sec}$ for Site 5 ($V_{s30} = 450\text{ m/sec}$).

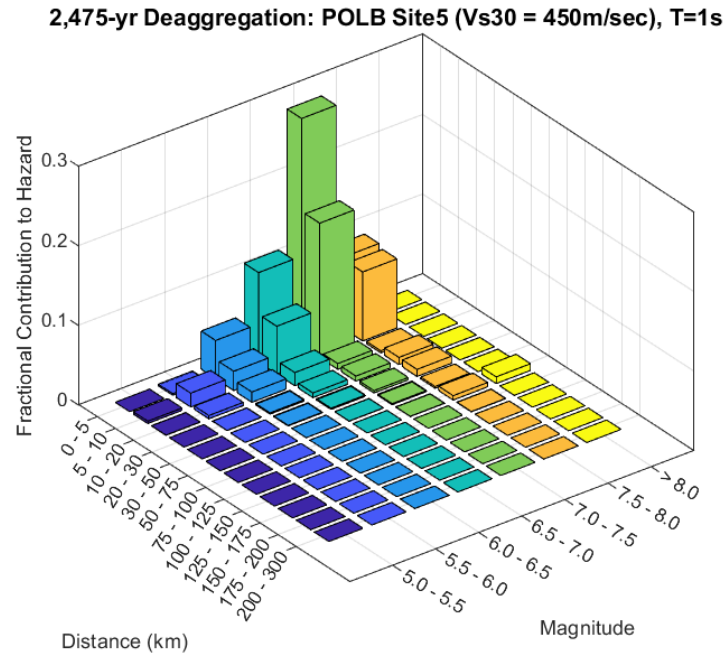


Figure 141. Magnitude-distance contribution for the 2,475-year hazard level for $T = 1.0$ sec for Site 5 ($V_{s30} = 450$ m/sec).

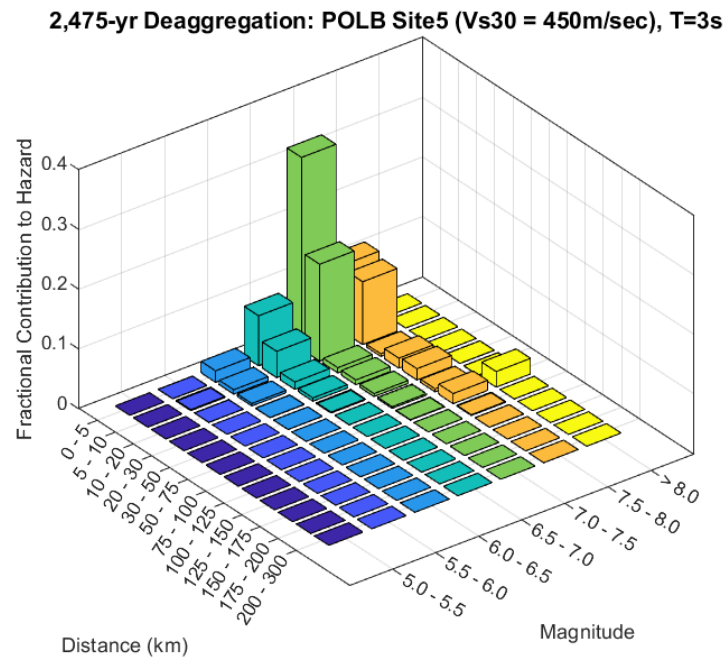


Figure 142. Magnitude-distance contribution for the 2,475-year hazard level for $T = 3.0$ sec for Site 5 ($V_{s30} = 450$ m/sec).

The hazard results for this site are not compared to results from the NSHM 2018 (NSHM18) and the NSHM 2023 (NSHM23). Given the proximity of the study sites, similar observations and trends are expected compared to the NSHMs results to those discussed in Section 4.2.1 for Site 1.

4.4.2 Site 5 Results with Directivity, $V_{S30} = 450$ m/sec

The results for Site 5 with $V_{S30} = 450$ m/sec with the inclusion of the directivity models are presented in this section. Note that the adjustments based on the directivity models only impact the longer spectral period ground motions (i.e., periods equal to and greater than 0.5 sec) and the results presented earlier for the shorter periods are unaffected by the directivity models. The mean total hazard curves for spectral periods of 1.0, 3.0, 5.0 and 10.0 seconds are plotted in Figures 143 through 146. In each plot, the individual hazard curves for each directivity model are plotted along with the weighted mean (dashed light blue line) using the assigned weights for the suite of directivity models. For comparison the mean hazard curve without directivity is also plotted (heavy black line).

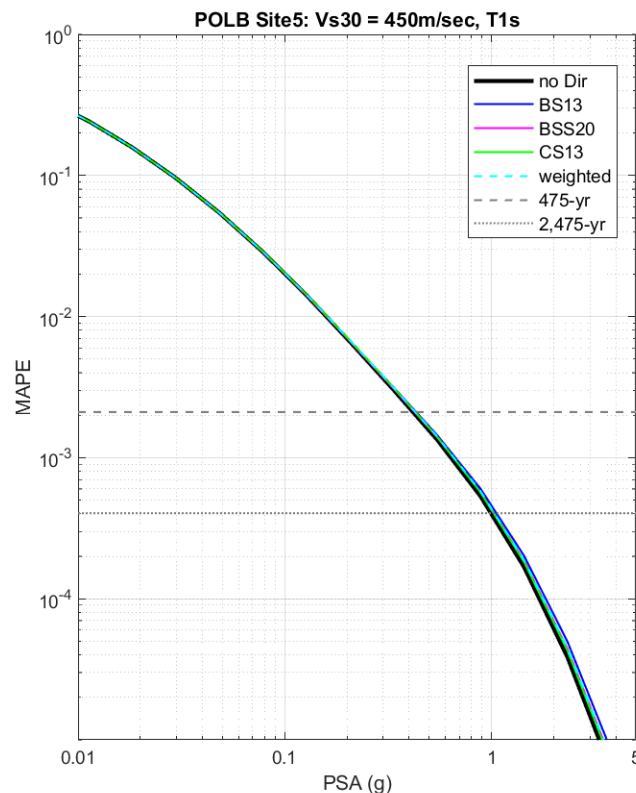


Figure 143. Total mean hazard curves without directivity (heavy black line), individual directivity models and weighted directivity results (dashed blue line) for Site 5 ($V_{S30} = 450$ m/sec) for $T=1.0$ sec spectral period. MAPE refers to mean annual probability of exceedance.

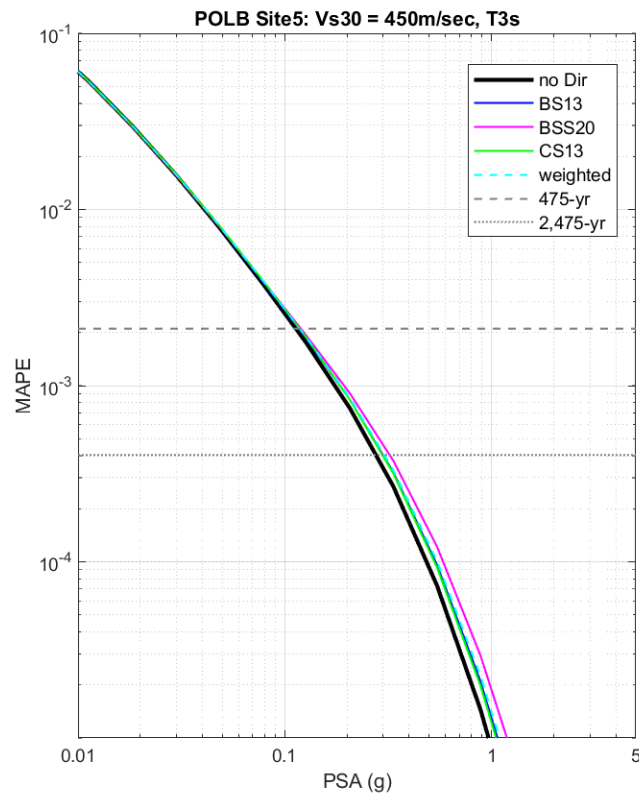


Figure 144. Total mean hazard curves without directivity (heavy black line), individual directivity models and weighted directivity results (dashed blue line) for Site 5 ($V_{s30} = 450$ m/sec) for $T=3.0$ sec spectral period. MAPE refers to mean annual probability of exceedance.

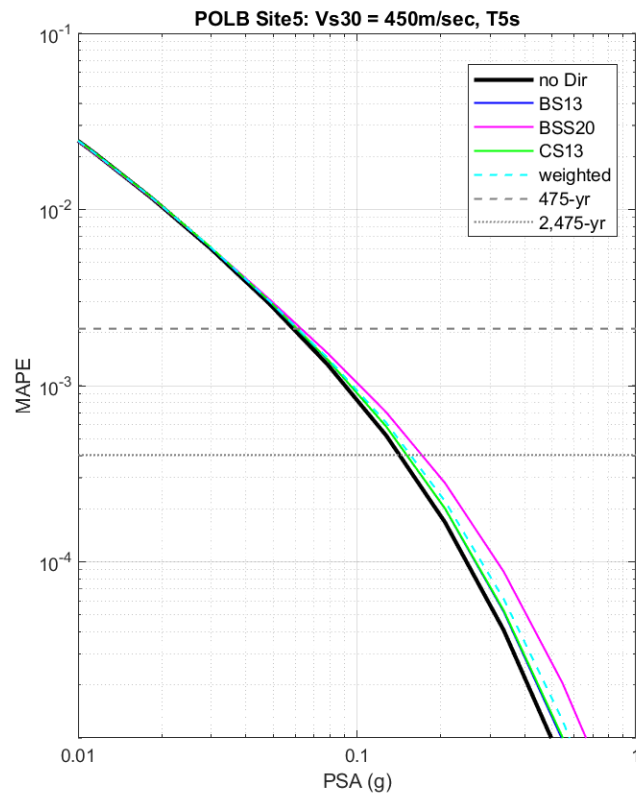


Figure 145. Total mean hazard curves without directivity (heavy black line), individual directivity models and weighted directivity results (dashed blue line) for Site 5 ($V_{s30} = 450$ m/sec) for $T=5.0$ sec spectral period. MAPE refers to mean annual probability of exceedance.

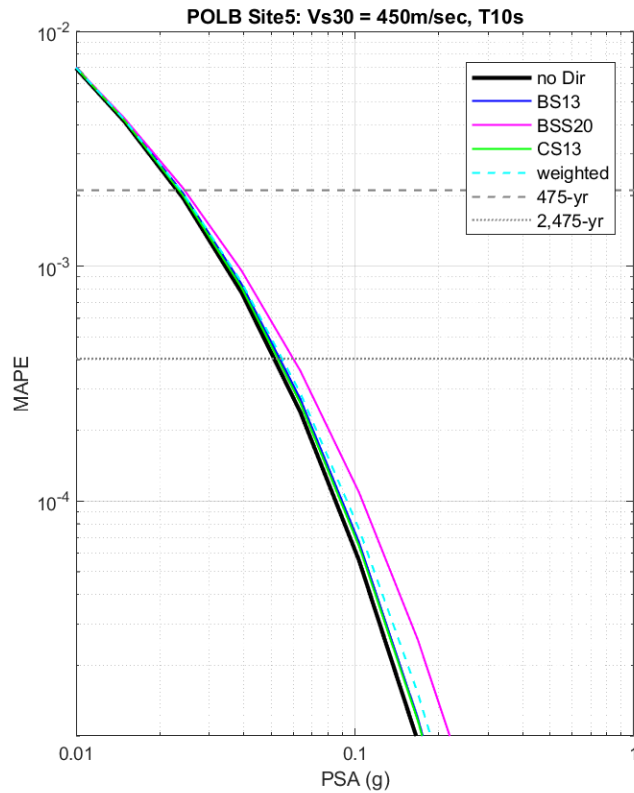


Figure 146. Total mean hazard curves without directivity (heavy black line), individual directivity models and weighted directivity results (dashed blue line) for Site 5 ($V_{s30} = 450$ m/sec) for $T=10.0$ sec spectral period. MAPE refers to mean annual probability of exceedance.

All of the directivity models show an increase in the hazard with the BSS20 model yielding the largest increase. To observe the impact on the ground motions from these directivity models, spectral ratios of the UHS ground motions are computed and plotted in Figure 147 through 150 for the selected four hazard levels. At the 72-year hazard level, there is minimal impact from the directivity models. For the longer return period levels, the results from the directivity models increase, especially for the longer spectral periods, beyond the period range of interest for this project. The UHS including the weighting combination of the directivity models for the four return period levels are listed in Table 27. The comparison of the UHS both with and without the directivity models are plotted in Figures 151 through 154 for the selected four hazard levels. Overall, the increase in the long-period ground motion due to directivity effects is observed to be 10% or less for the weighted directivity models. Similar deaggregation results are observed for the directivity cases and are not presented in the report.

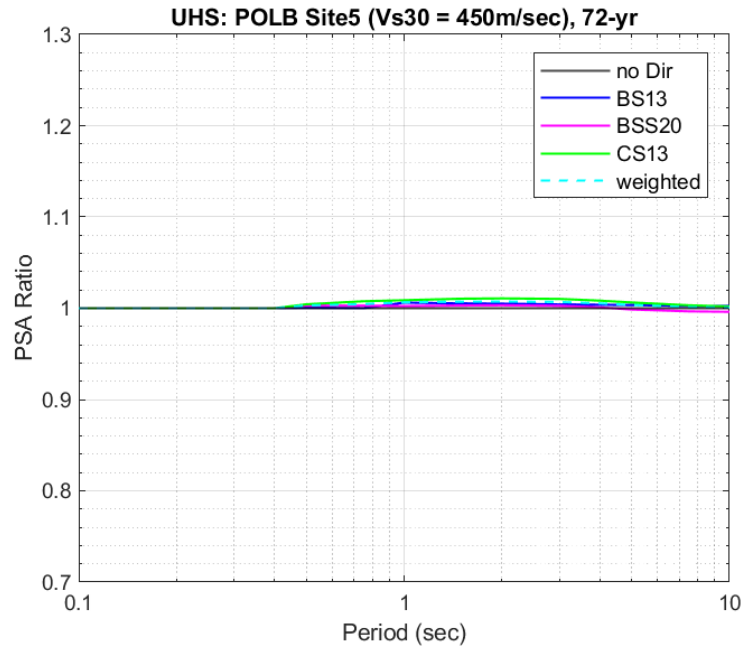


Figure 147. UHS spectral ratio for Site 5 ($V_{s30} = 450$ m/sec) for the 72-year return period hazard level for the individual and weighted combination directivity models.

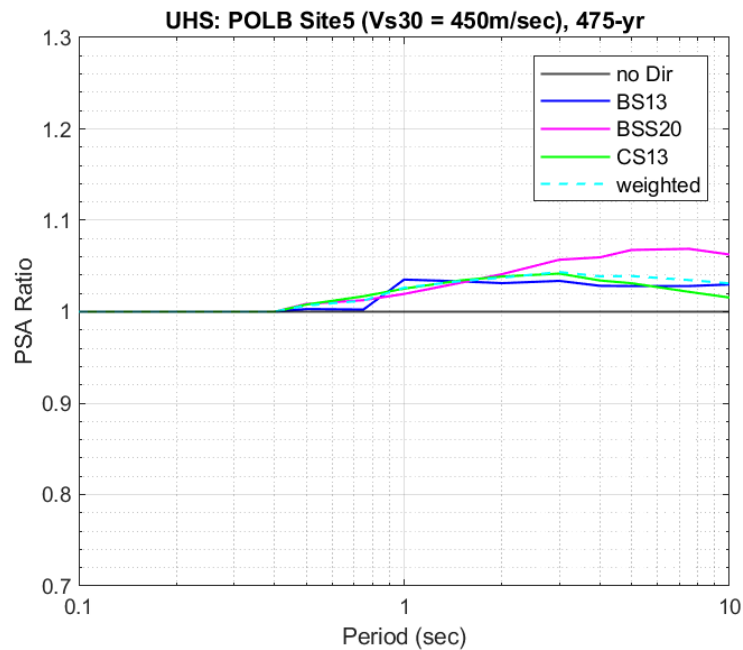


Figure 148. UHS spectral ratio for Site 5 ($V_{s30} = 450$ m/sec) for the 475-year return period hazard level for the individual and weighted combination directivity models.

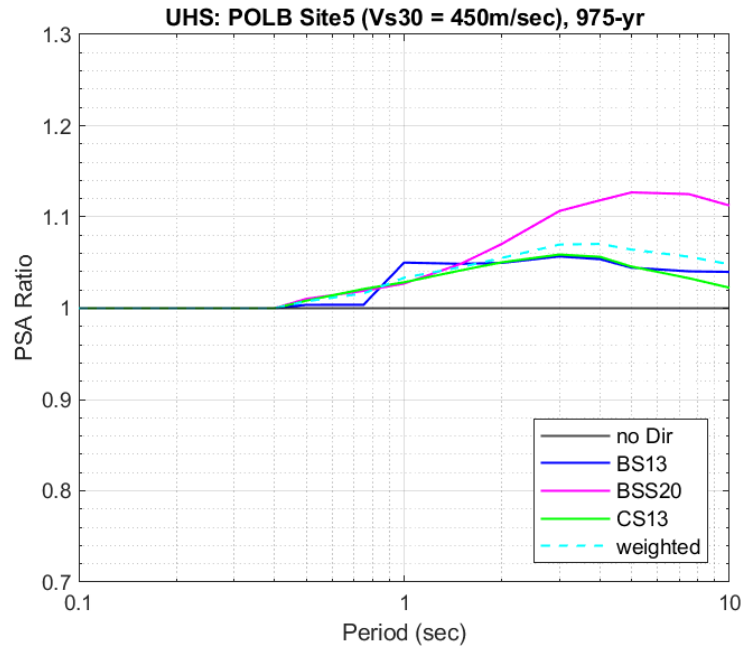


Figure 149. UHS spectral ratio for Site 5 ($V_{s30} = 450$ m/sec) for the 975-year return period hazard level for the individual and weighted combination directivity models.

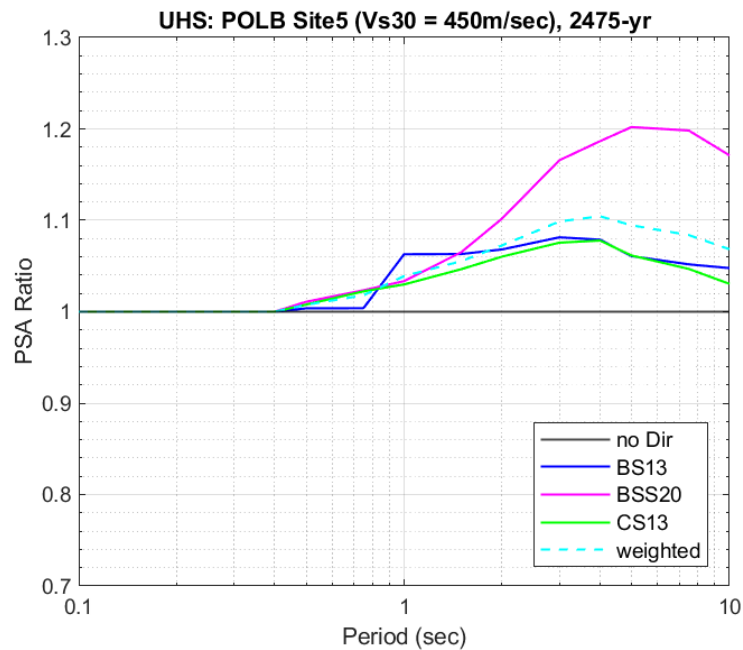


Figure 150. UHS spectral ratio for Site 5 ($V_{s30} = 450$ m/sec) for the 2,475-year return period hazard level for the individual and weighted combination directivity models.

Table 27. Horizontal UHS for Site 5 ($V_{S30} = 450$ m/sec) at the four hazard levels with the inclusion of the combined weighted directivity models.

Period (sec)	72-year Horizontal PSA (g)	475-year Horizontal PSA (g)	975-year Horizontal PSA (g)	2,475-year Horizontal PSA (g)
0.01	0.1583	0.4578	0.6342	0.9132
0.02	0.1595	0.4641	0.6429	0.9249
0.03	0.1701	0.4969	0.6847	0.9794
0.04	0.1884	0.5511	0.7567	1.0733
0.05	0.2086	0.6025	0.8400	1.1869
0.075	0.2664	0.7639	1.0501	1.5086
0.1	0.3180	0.9026	1.2276	1.7381
0.15	0.3712	1.0453	1.4523	2.0278
0.2	0.3794	1.0893	1.5283	2.1810
0.25	0.3669	1.0765	1.5309	2.2311
0.3	0.3465	1.0293	1.4830	2.1788
0.4	0.2957	0.8982	1.2924	1.9301
0.5	0.2554	0.7901	1.1480	1.7480
0.75	0.1782	0.5674	0.8484	1.3213
1	0.1303	0.4287	0.6498	1.0338
1.5	0.0804	0.2705	0.4140	0.6663
2	0.0554	0.1913	0.2948	0.4778
3	0.0329	0.1182	0.1843	0.3032
4	0.0223	0.0825	0.1288	0.2114
5	0.0161	0.0614	0.0952	0.1554
7.5	0.0089	0.0360	0.0543	0.0855
10	0.0056	0.0238	0.0355	0.0548

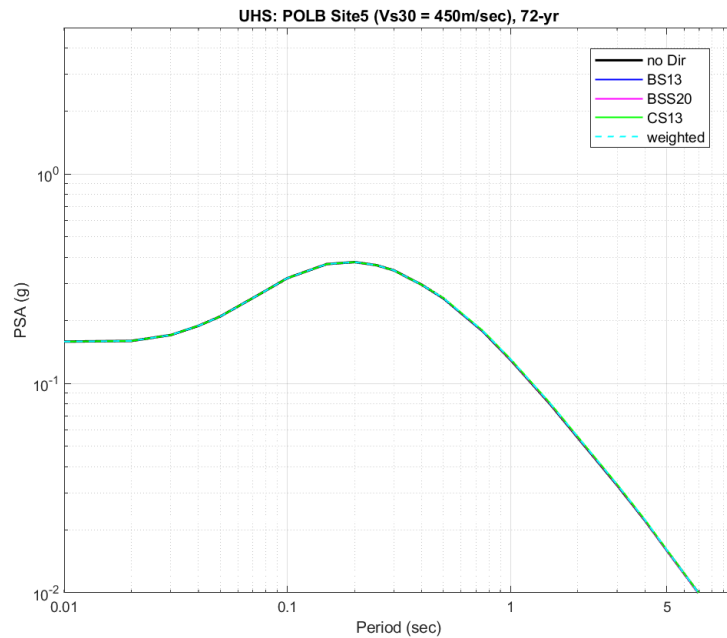


Figure 151. Uniform hazard spectra for Site 5 ($V_{S30} = 450$ m/sec) without directivity (black line) and with the individual and combined weighted (dashed blue line) directivity models for the 72-year return period.

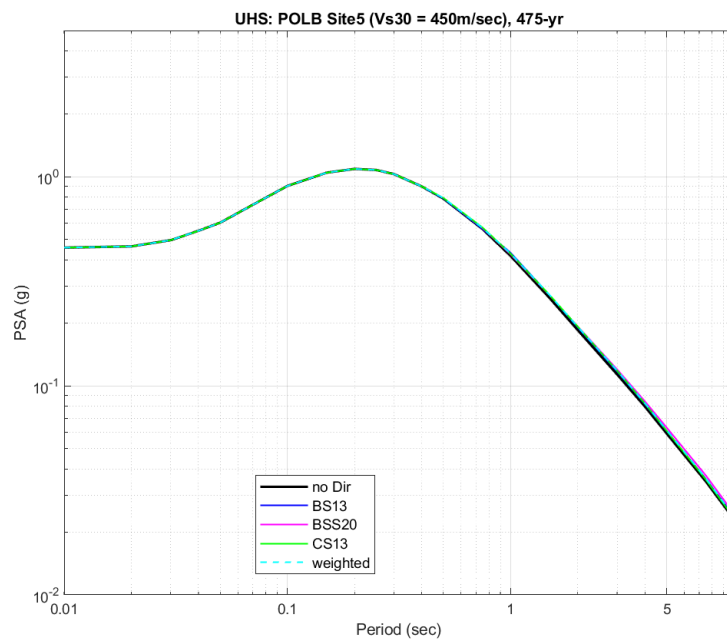


Figure 152. Uniform hazard spectra for Site 5 ($V_{S30} = 450$ m/sec) without directivity (black line) and with the individual and combined weighted (dashed blue line) directivity models for the 475-year return period.

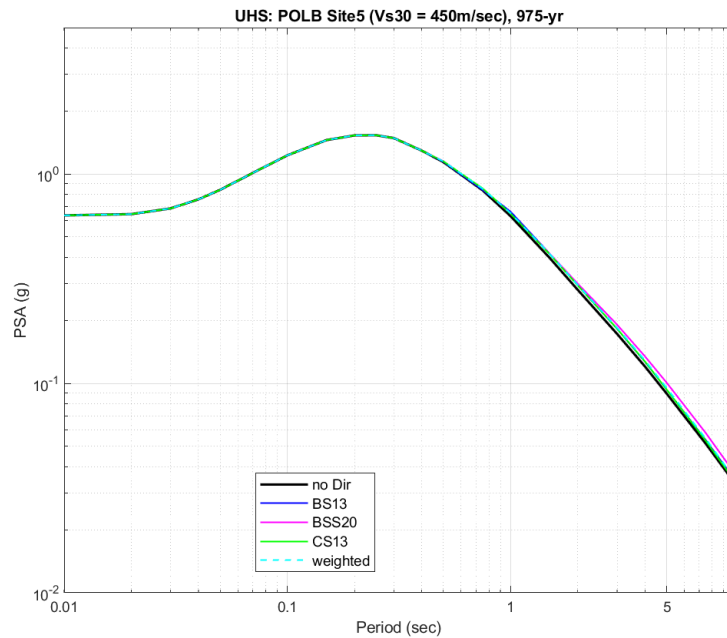


Figure 153. Uniform hazard spectra for Site 5 ($V_{S30} = 450$ m/sec) without directivity (black line) and with the individual and combined weighted (dashed blue line) directivity models for the 975-year return period.

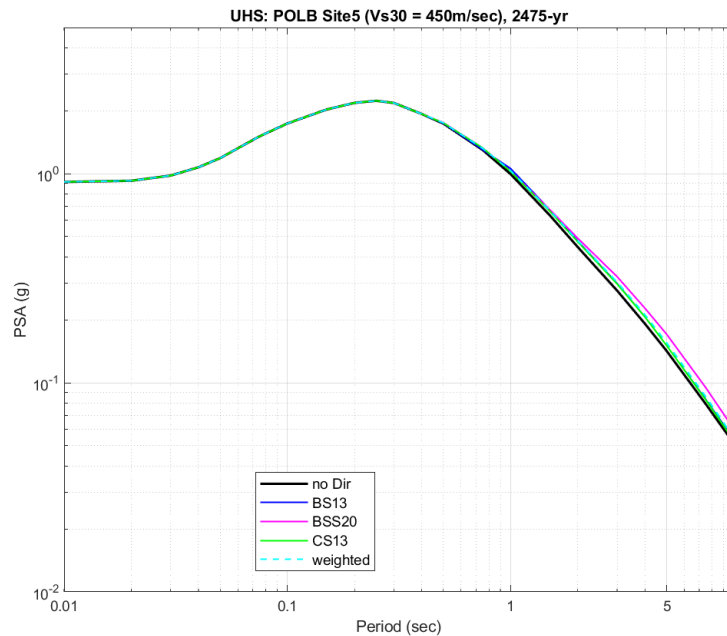


Figure 154. Uniform hazard spectra for Site 5 ($V_{S30} = 450$ m/sec) without directivity (black line) and with the individual and combined weighted (dashed blue line) directivity models for the 2,475-year return period.

Only the Bayless and Somerville (2013) directivity model is defined for the fault normal and fault parallel components of motions including directivity. The other directivity models are defined for the average horizontal component including directivity. Thus, ground motions are computed based on the application of only the Bayless and Somerville (2013) directivity model for the three cases of average horizontal, fault normal and fault parallel components. The resulting UHS for the selected four return period hazard levels are plotted in Figure 155 through 158 and listed in Table 28 through Table 30. The spectral ratio results for are plotted in Figure 159 through 162 for the selected return periods. These results show a small impact from the application of the BS13 directivity model for the 72-yr hazard level. The impact, however, increases with increasing return period hazard level and as well spectral period. For the longer return period hazard levels and longer spectral periods, the fault normal results are increased up to about 16% relative to the average horizontal component with directivity. For the fault parallel component, the ground motions are observed to approach a reduction of approximately 10% relative to the average horizontal component.

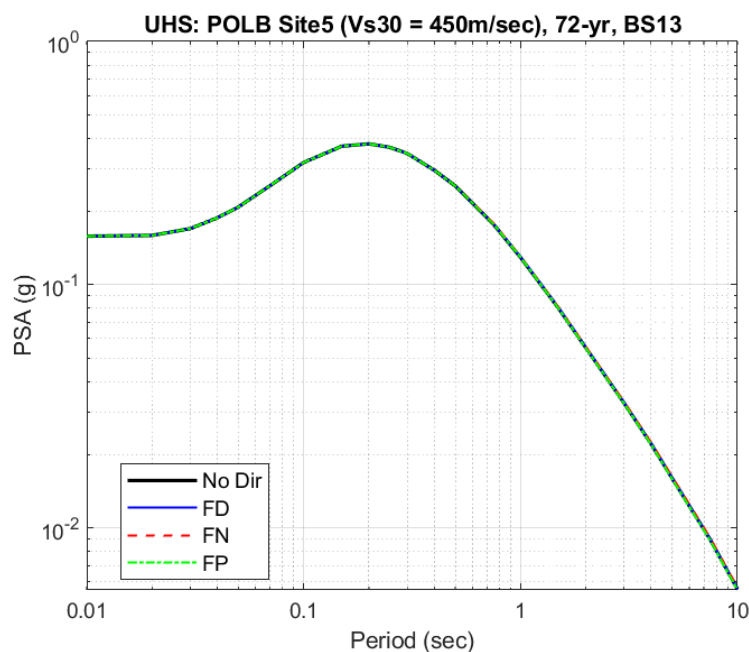


Figure 155. Uniform hazard spectra for Site 5 ($V_{s30} = 450$ m/sec) without directivity (black line) and with the BS13 directivity model for average horizontal (FD), fault normal (FN) and fault parallel (FP) components for the 72-year return period.

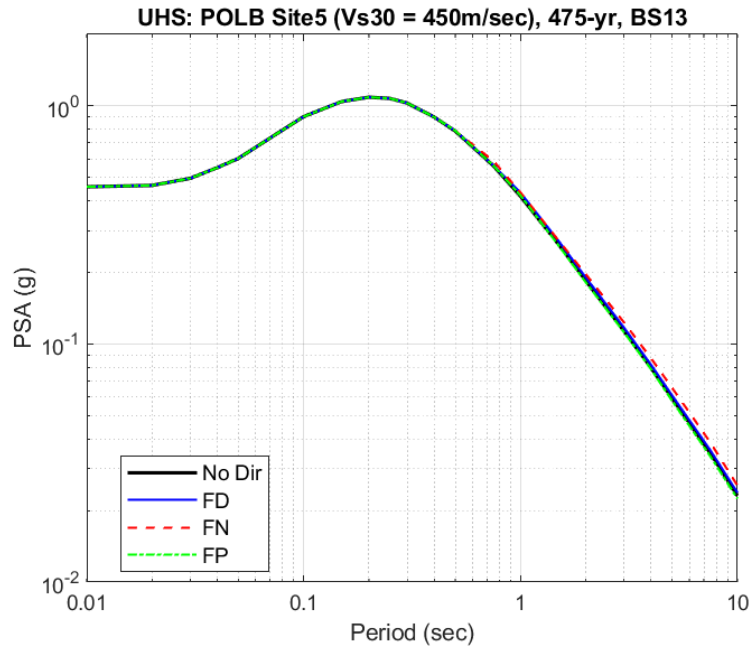


Figure 156. Uniform hazard spectra for Site 5 ($V_{s30} = 450$ m/sec) without directivity (black line) and with the BS13 directivity model for average horizontal (FD), fault normal (FN) and fault parallel (FP) components for the 475-year return period.

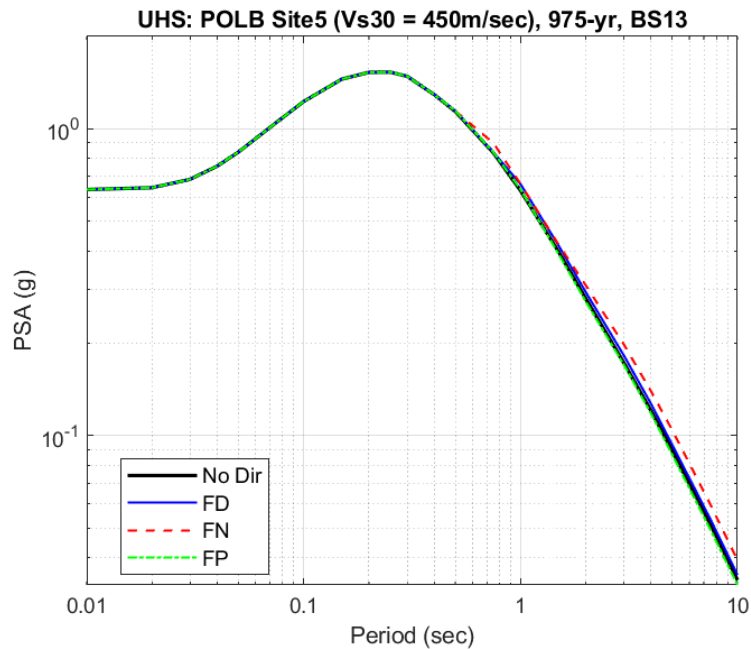


Figure 157. Uniform hazard spectra for Site 5 ($V_{s30} = 450$ m/sec) without directivity (black line) and with the BS13 directivity model for average horizontal (FD), fault normal (FN) and fault parallel (FP) components for the 975-year return period.

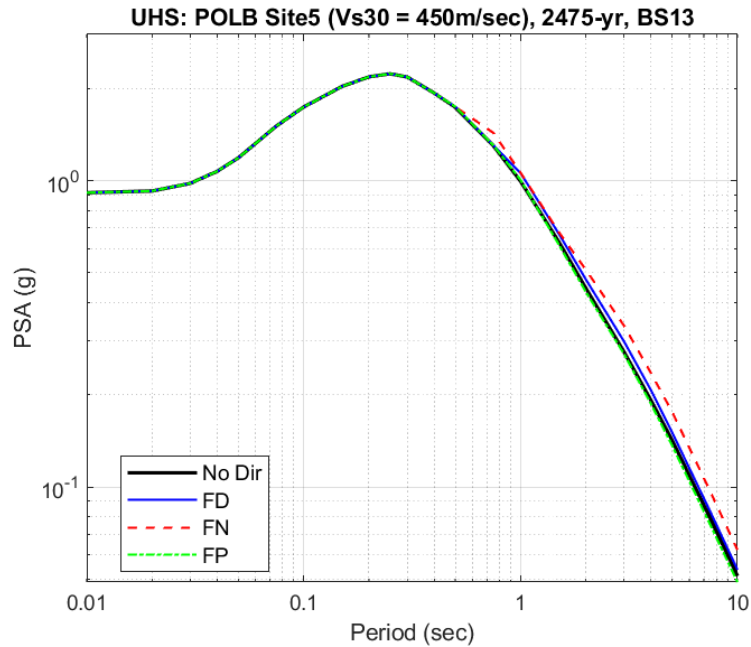


Figure 158. Uniform hazard spectra for Site 5 ($V_{s30} = 450\text{ m/sec}$) without directivity (black line) and with the BS13 directivity model for average horizontal (FD), fault normal (FN) and fault parallel (FP) components for the 2,475-year return period.

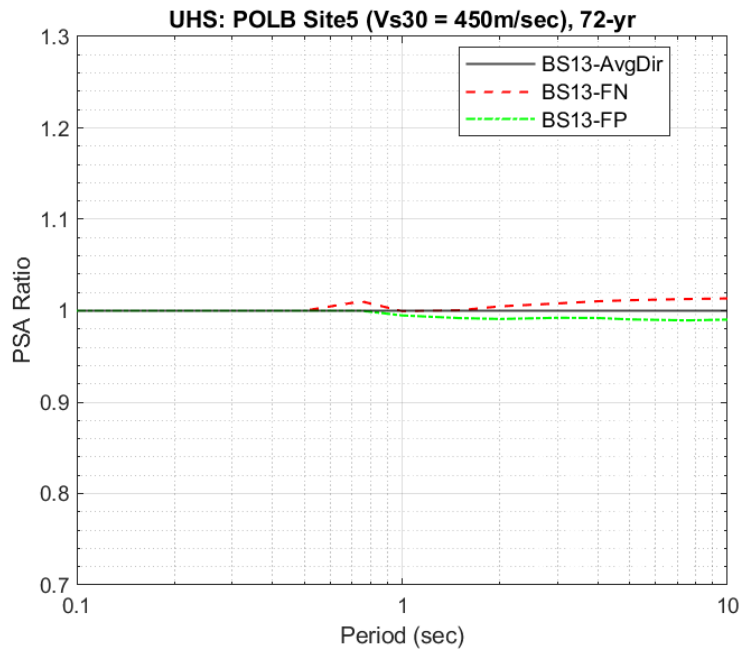


Figure 159. UHS spectral ratio for Site 5 ($V_{s30} = 450\text{ m/sec}$) for the 72-year return period hazard level for the individual horizontal components of the BS13 directivity models.

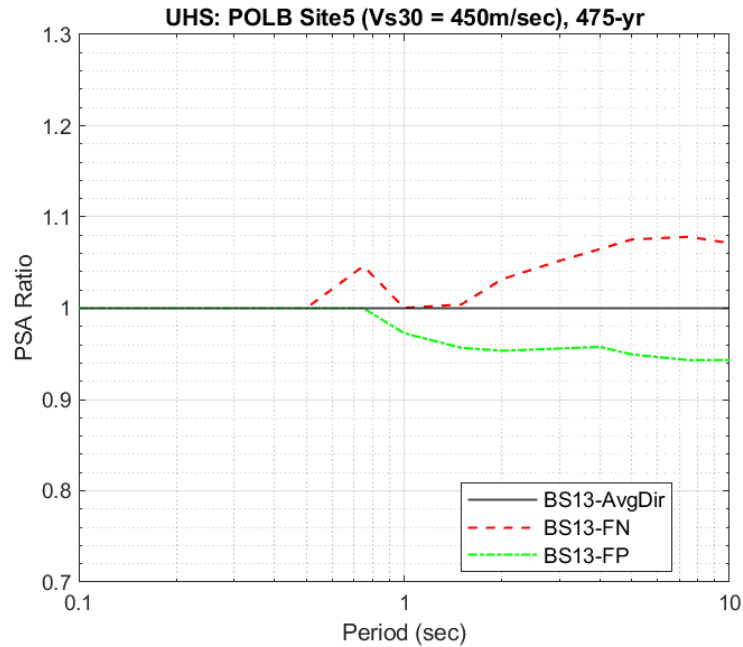


Figure 160. UHS spectral ratio for Site 5 ($V_{s30} = 450\text{ m/sec}$) for the 475-year return period hazard level for the individual horizontal components of the BS13 directivity models.

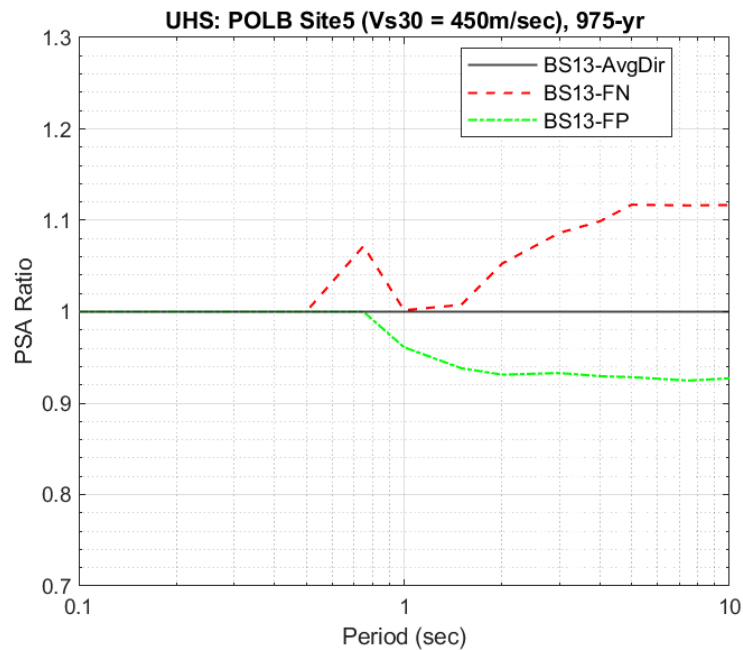


Figure 161. UHS spectral ratio for Site 5 ($V_{s30} = 450\text{ m/sec}$) for the 975-year return period hazard level for the individual horizontal components of the BS13 directivity models.

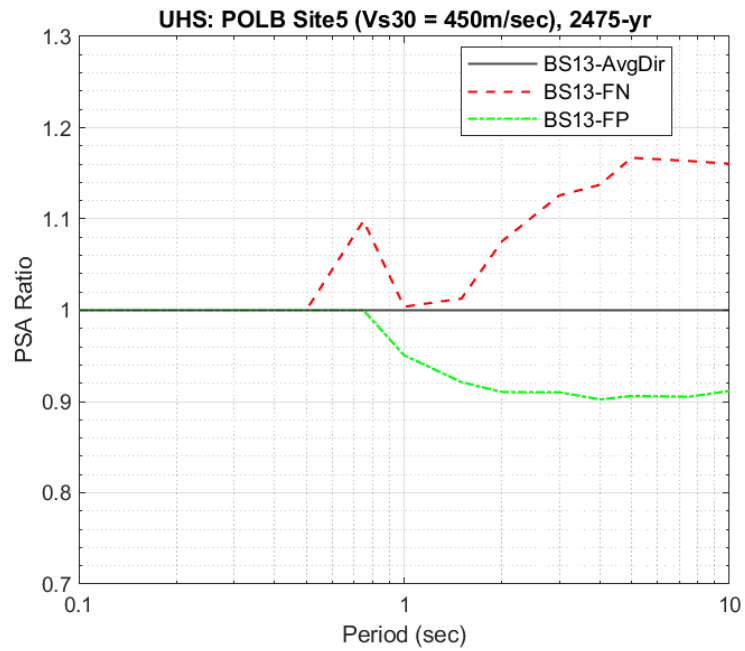


Figure 162. UHS spectral ratio for Site 5 ($V_{s30} = 450$ m/sec) for the 2,475-year return period hazard level for the individual horizontal components of the BS13 directivity models.

Table 28. Horizontal UHS for Site 5 ($V_{S30} = 450$ m/sec) at the four hazard levels with the inclusion of the BS13 directivity models for the average horizontal component.

Period (sec)	72-year Horizontal BS13 (FD) PSA (g)	475-year Horizontal BS13 (FD) PSA (g)	975-year Horizontal BS13 (FD) PSA (g)	2,475-year Horizontal BS13 (FD) PSA (g)
0.01	0.1583	0.4578	0.6342	0.9132
0.02	0.1595	0.4641	0.6429	0.9249
0.03	0.1701	0.4969	0.6847	0.9794
0.04	0.1884	0.5511	0.7567	1.0733
0.05	0.2086	0.6025	0.8400	1.1869
0.075	0.2664	0.7639	1.0501	1.5086
0.1	0.3180	0.9026	1.2276	1.7381
0.15	0.3712	1.0453	1.4523	2.0278
0.2	0.3794	1.0893	1.5283	2.1810
0.25	0.3669	1.0765	1.5309	2.2311
0.3	0.3465	1.0293	1.4830	2.1788
0.4	0.2957	0.8982	1.2924	1.9301
0.5	0.2548	0.7871	1.1436	1.7414
0.75	0.1774	0.5619	0.8379	1.3030
1	0.1303	0.4324	0.6602	1.0576
1.5	0.0802	0.2704	0.4154	0.6712
2	0.0553	0.1902	0.2933	0.4758
3	0.0328	0.1171	0.1820	0.2984
4	0.0222	0.0817	0.1267	0.2065
5	0.0161	0.0608	0.0934	0.1506
7.5	0.0090	0.0358	0.0534	0.0830
10	0.0056	0.0237	0.0352	0.0537

Table 29. Horizontal UHS for Site 5 ($V_{S30} = 450$ m/sec) at the four hazard levels with the inclusion of the BS13 directivity models for the fault normal (FN) component.

Period (sec)	72-year Horizontal BS13 (FN) PSA (g)	475-year Horizontal BS13 (FN) PSA (g)	975-year Horizontal BS13 (FN) PSA (g)	2,475-year Horizontal BS13 (FN) PSA (g)
0.01	0.1583	0.4578	0.6342	0.9132
0.02	0.1595	0.4641	0.6429	0.9249
0.03	0.1701	0.4969	0.6847	0.9794
0.04	0.1884	0.5511	0.7567	1.0733
0.05	0.2086	0.6025	0.8400	1.1869
0.075	0.2664	0.7639	1.0501	1.5086
0.1	0.3180	0.9026	1.2276	1.7381
0.15	0.3712	1.0453	1.4523	2.0278
0.2	0.3794	1.0893	1.5283	2.1810
0.25	0.3669	1.0765	1.5309	2.2311
0.3	0.3465	1.0293	1.4830	2.1788
0.4	0.2957	0.8982	1.2924	1.9301
0.5	0.2548	0.7871	1.1436	1.7414
0.75	0.1792	0.5879	0.8981	1.4307
1	0.1302	0.4325	0.6613	1.0617
1.5	0.0803	0.2716	0.4185	0.6797
2	0.0556	0.1963	0.3087	0.5118
3	0.0330	0.1232	0.1977	0.3360
4	0.0224	0.0870	0.1393	0.2348
5	0.0162	0.0654	0.1043	0.1758
7.5	0.0091	0.0386	0.0597	0.0966
10	0.0057	0.0254	0.0393	0.0623

Table 30. Horizontal UHS for Site 5 ($V_{S30} = 450$ m/sec) at the four hazard levels with the inclusion of the BS13 directivity models for the fault parallel (FP) component.

Period (sec)	72-year Horizontal BS13 (FP) PSA (g)	475-year Horizontal BS13 (FP) PSA (g)	975-year Horizontal BS13 (FP) PSA (g)	2,475-year Horizontal BS13 (FP) PSA (g)
0.01	0.1583	0.4578	0.6342	0.9132
0.02	0.1595	0.4641	0.6429	0.9249
0.03	0.1701	0.4969	0.6847	0.9794
0.04	0.1884	0.5511	0.7567	1.0733
0.05	0.2086	0.6025	0.8400	1.1869
0.075	0.2664	0.7639	1.0501	1.5086
0.1	0.3180	0.9026	1.2276	1.7381
0.15	0.3712	1.0453	1.4523	2.0278
0.2	0.3794	1.0893	1.5283	2.1810
0.25	0.3669	1.0765	1.5309	2.2311
0.3	0.3465	1.0293	1.4830	2.1788
0.4	0.2957	0.8982	1.2924	1.9301
0.5	0.2548	0.7871	1.1436	1.7414
0.75	0.1774	0.5619	0.8379	1.3030
1	0.1296	0.4205	0.6345	1.0054
1.5	0.0796	0.2587	0.3897	0.6184
2	0.0548	0.1814	0.2731	0.4332
3	0.0325	0.1120	0.1698	0.2716
4	0.0220	0.0782	0.1178	0.1863
5	0.0159	0.0577	0.0867	0.1365
7.5	0.0089	0.0337	0.0494	0.0751
10	0.0056	0.0224	0.0326	0.0490

4.5 Site 8 Results

4.5.1 Site 8 Results without Directivity, $V_{S30} = 450$ m/sec

The mean hazard curves including the Wilmington fault for Site 8 are shown in Figures 163 through 166 for PGA and spectral periods of 0.2, 1, and 3 sec. For the longer spectral periods (i.e., 1 and 3 sec), these plots show the horizontal component without the inclusion of the directivity models. In these plots, individual hazard curves from the scenario fault ruptures from the UCERF3 faults, gridded sources, the Wilmington fault as well as the combined total hazard are presented. Hazard levels corresponding to the 475 and 2,475-year return periods are also plotted in the figures. For the short to intermediate spectral periods, the hazard is equally

controlled by the UCERF3 grid and fault sources for hazard levels of about 100 to 200 years. For shorter return periods and the intermediate to short periods, the hazard is controlled by the gridded source. For longer return periods and as well longer spectral periods, the hazard is controlled by the UCERF3 fault sources. For all cases, the contribution from the Wilmington fault is less than from the other UCERF3 sources.

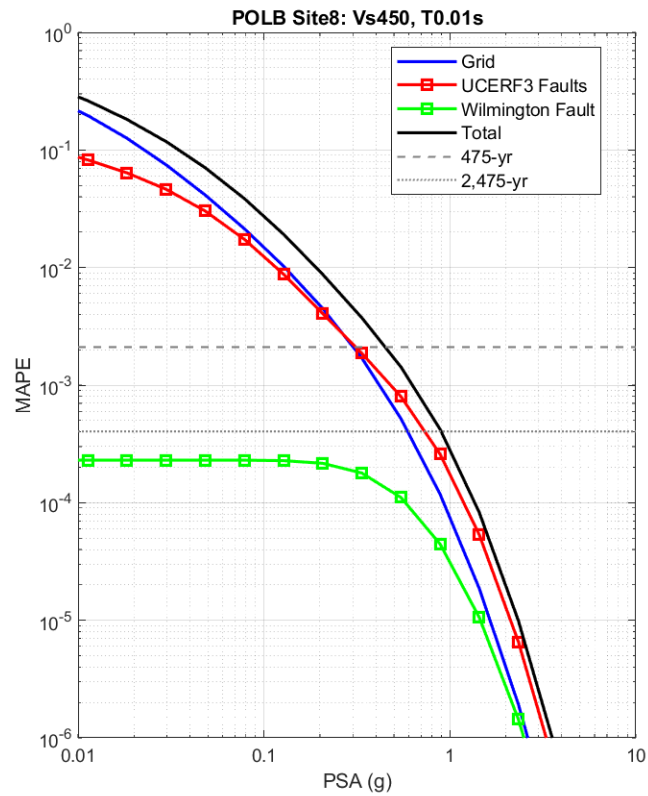


Figure 163. Mean horizontal component hazard curves from the UCERF3 gridded and fault sources, Wilmington fault, and total mean hazard for PGA for Site 8 for $V_{s30} = 450$ m/sec without directivity. MAPE refers to mean annual probability of exceedance.

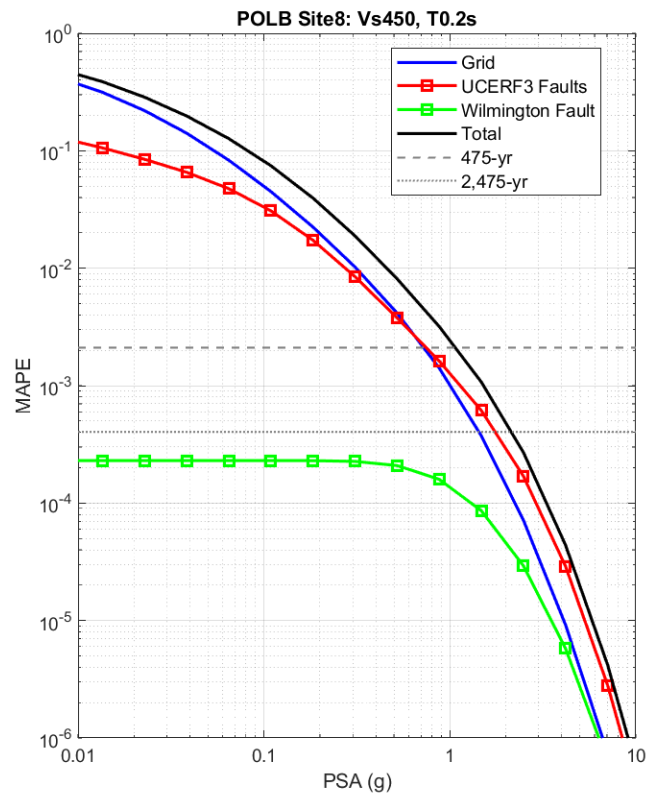


Figure 164. Mean horizontal component hazard curves from the UCERF3 gridded and fault sources, Wilmington fault, and total mean hazard for $T=0.2$ sec for Site 8 for $V_{S30} = 450$ m/sec without directivity. MAPE refers to mean annual probability of exceedance.

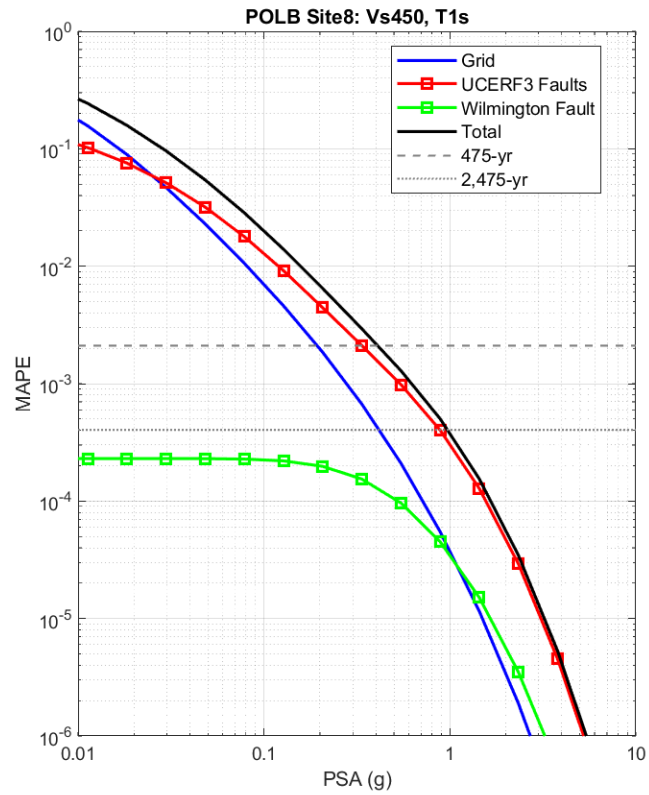


Figure 165. Mean horizontal component hazard curves from the UCERF3 gridded and fault sources, Wilmington fault, and total mean hazard for $T=1.0$ sec for Site 8 for $V_{s30} = 450$ m/sec without directivity. MAPE refers to mean annual probability of exceedance.

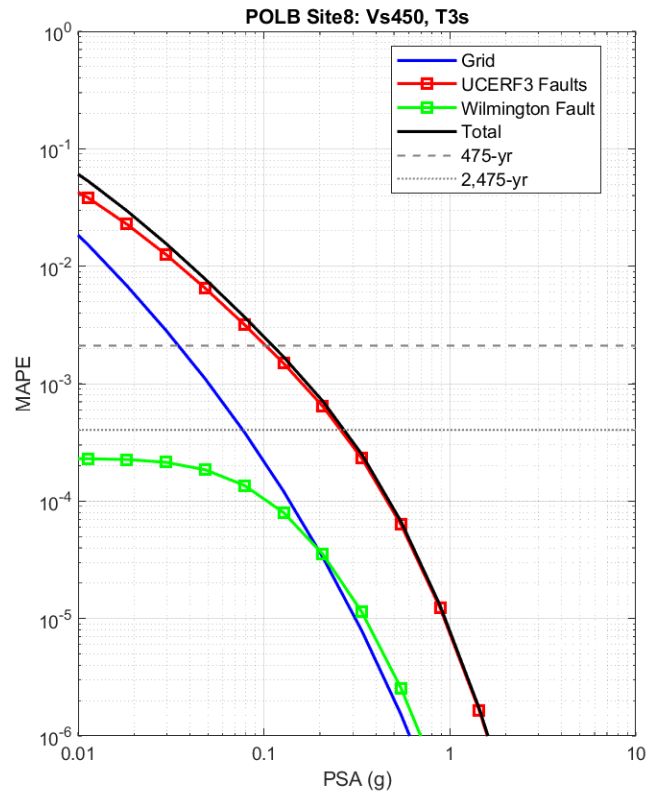


Figure 166. Mean horizontal component hazard curves from the UCERF3 gridded and fault sources, Wilmington fault, and total mean hazard for $T=3.0$ sec for Site 8 for $V_{s30} = 450$ m/sec without directivity. MAPE refers to mean annual probability of exceedance.

To further illustrate the contribution from the parent fault systems from the UCERF3 database and the Wilmington fault, the ranked top 15 contributing parent fault hazard curves at the 2,475-year hazard level are plotted along with the total combined hazard curve from just fault sources including the Wilmington fault. These results are plotted in Figures 167 through 170 for the same previous four spectral periods. Note that given the change in the relative ranking order the line and symbol type for a given parent fault varies from one plot to another. The largest contributing parent fault system to the total fault hazard is the Palos Verdes fault which is an expected result given the close distance to the site and the assigned slip rate for this fault relative to the other faults in the area. The Wilmington fault has a similar contribution to the Compton fault for the intermediate and short periods and a lesser contribution at the longer spectral periods.

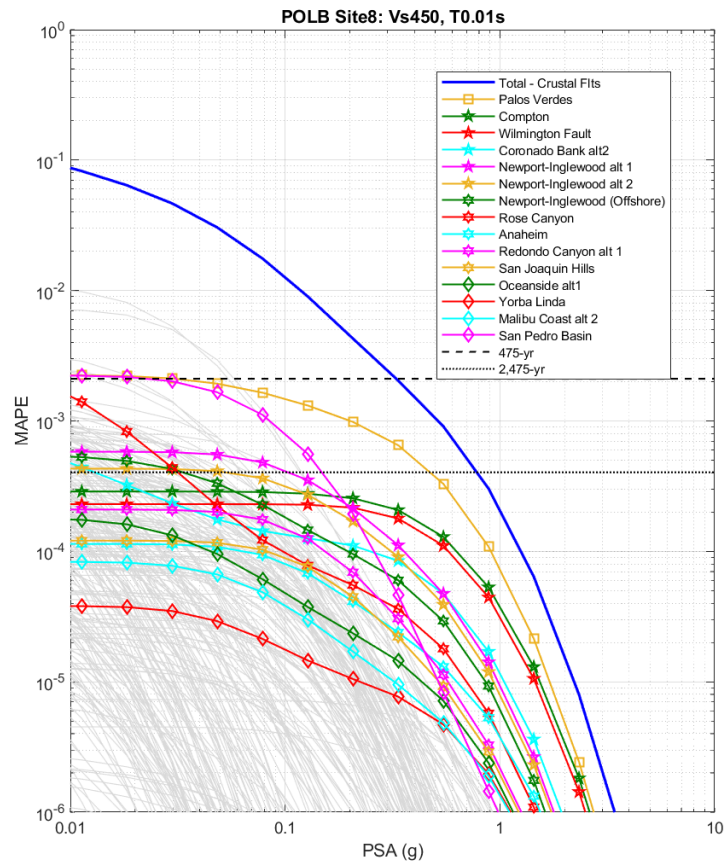


Figure 167. Mean horizontal component hazard curves from the Wilmington and UCERF3 parent fault sources at PGA for Site 8 for $V_{s30} = 450$ m/sec without directivity. The colored individual-fault hazard curves show the top contributing parent faults to the total hazard from crustal faults. MAPE refers to mean annual probability of exceedance.

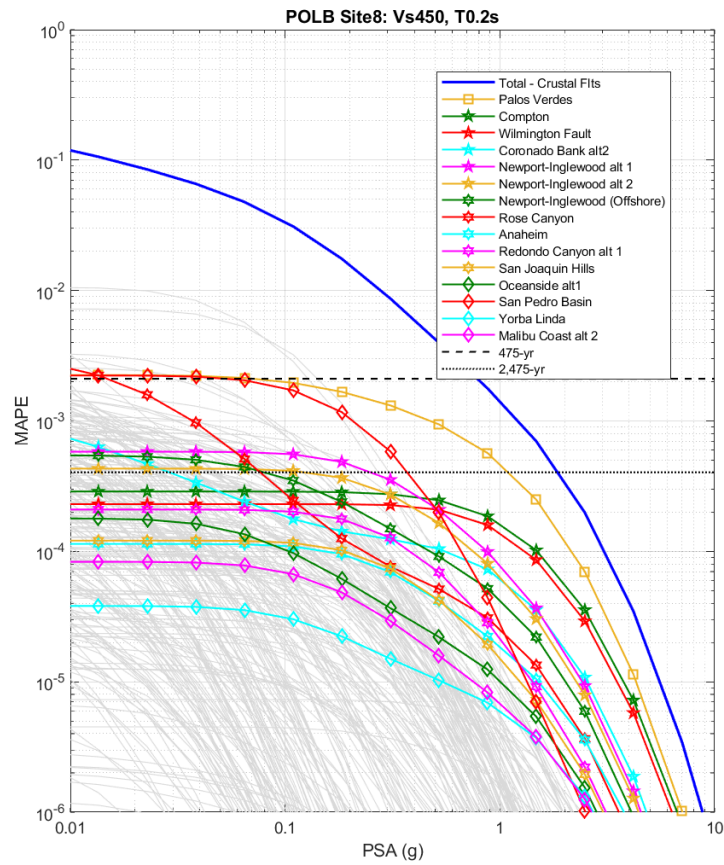


Figure 168. Mean horizontal component hazard curves from the Wilmington and UCERF3 parent fault sources at $T=0.2$ sec for Site 8 for $V_{s30} = 450$ m/sec without directivity. The colored individual-fault hazard curves show the top contributing parent faults to the total hazard from crustal faults. MAPE refers to mean annual probability of exceedance.

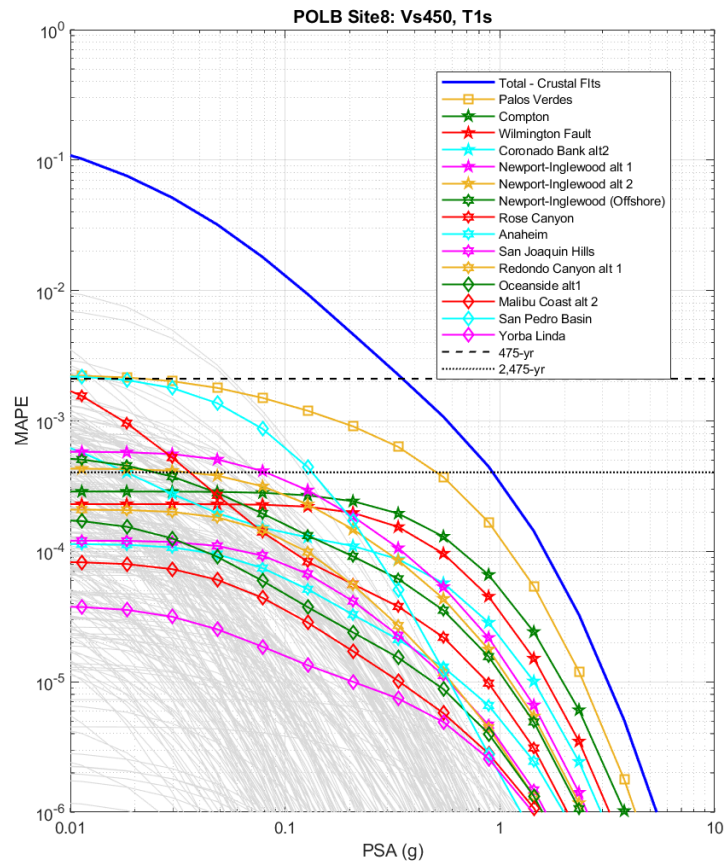


Figure 169. Mean horizontal component hazard curves from the Wilmington and UCERF3 parent fault sources at $T=1.0$ sec for Site 8 for $V_{s30} = 450$ m/sec without directivity. The colored individual-fault hazard curves show the top contributing parent faults to the total hazard from crustal faults. MAPE refers to mean annual probability of exceedance.

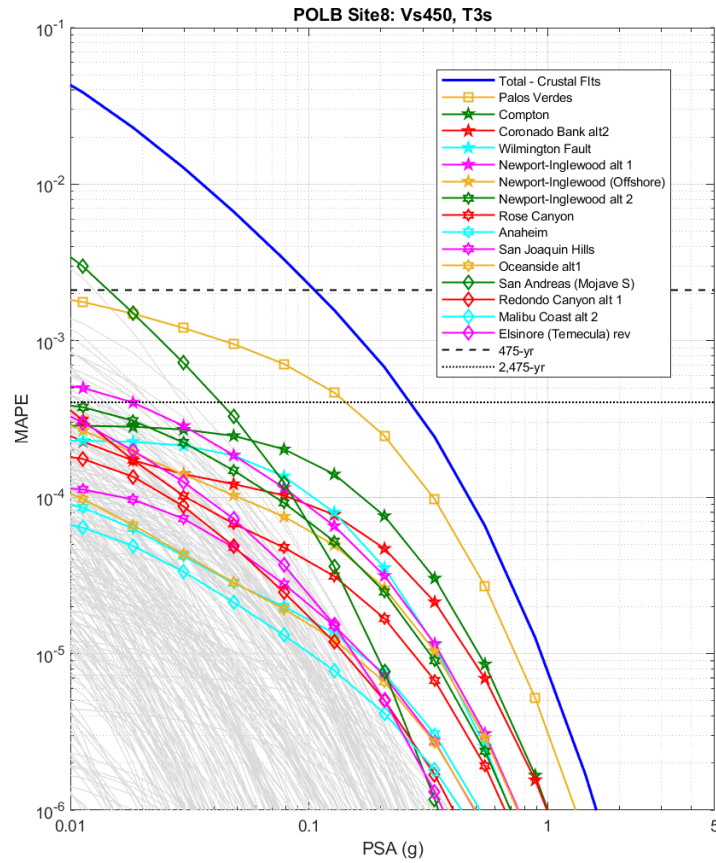


Figure 170. Mean horizontal component hazard curves from the Wilmington and UCERF3 parent fault sources at $T=3.0$ sec for Site 8 for $V_{s30} = 450$ m/sec without directivity. The colored individual-fault hazard curves show the top contributing parent faults to the total hazard from crustal faults. MAPE refers to mean annual probability of exceedance.

Given the hazard curves for the full suite of spectral periods, the computed uniform hazard spectra (UHS) for the selected 72, 475, 975 and 2,475-year return period hazard levels are plotted in Figure 171 for the average horizontal component without the inclusion of the directivity models. These horizontal UHS values for the return period hazard levels at all spectral periods are given in Table 31.

Table 31. Horizontal UHS for Site 8 ($V_{S30} = 450$ m/sec) at the suite of hazard levels without the inclusion of the directivity models.

Period (sec)	72-year Horizontal PSA (g)	475-year Horizontal PSA (g)	975-year Horizontal PSA (g)	2,475-year Horizontal PSA (g)
0.01	0.1562	0.4486	0.6220	0.8966
0.02	0.1573	0.4546	0.6302	0.9078
0.03	0.1677	0.4867	0.6708	0.9607
0.04	0.1857	0.5407	0.7406	1.0518
0.05	0.2057	0.5915	0.8216	1.1619
0.075	0.2627	0.7491	1.0306	1.4821
0.1	0.3135	0.8878	1.2040	1.7066
0.15	0.3663	1.0268	1.4224	1.9886
0.2	0.3744	1.0689	1.5017	2.1344
0.25	0.3622	1.0553	1.5020	2.1792
0.3	0.3422	1.0088	1.4495	2.1261
0.4	0.2920	0.8807	1.2615	1.8838
0.5	0.2518	0.7678	1.1127	1.6939
0.75	0.1755	0.5491	0.8130	1.2600
1	0.1282	0.4086	0.6134	0.9686
1.5	0.0791	0.2564	0.3868	0.6149
2	0.0545	0.1809	0.2730	0.4338
3	0.0324	0.1113	0.1686	0.2689
4	0.0220	0.0783	0.1179	0.1867
5	0.0159	0.0583	0.0880	0.1393
7.5	0.0089	0.0344	0.0507	0.0778
10	0.0056	0.0228	0.0335	0.0506

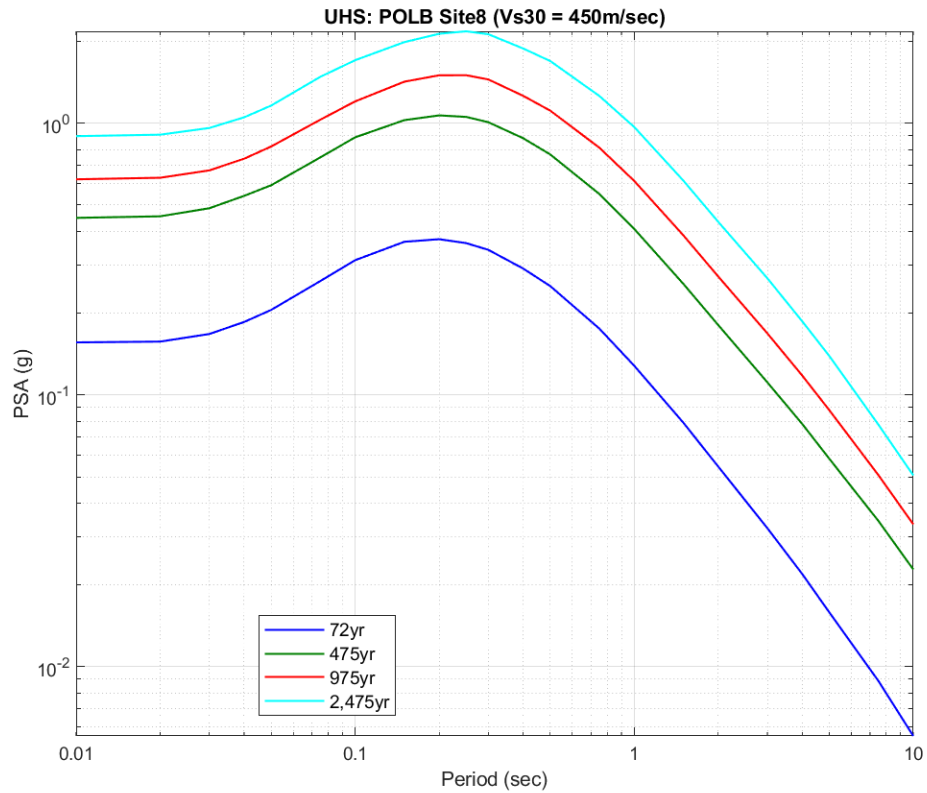


Figure 171. Uniform hazard spectra for Site 8 ($V_{s30} = 450$ m/sec) without the inclusion of the directivity model.

The mean magnitude, distance, and epsilon values for the horizontal component without the directivity models are plotted in Figures 172 to 174 for the selected four hazard levels. These results are plotted as a function of spectral period. In general, the magnitude increases with the increasing return period and spectral periods. For the mean distance values, the distances also decrease as a function of increasing return period but are larger for the longer spectral period given the greater distance to the larger magnitude faults in the region (e.g., San Andreas fault). Finally, the mean epsilon values increase as a function of increasing return periods with the results for the 2,475-year greater than approximately 1 over most of the spectral period range. The mean magnitude, distance, and epsilon values are listed in Tables 32 through 34 for the four hazard levels.

Table 32. Mean magnitude for the four hazard levels for Site 8 ($V_{S30} = 450$ m/sec) without the inclusion of the directivity models.

Period (sec)	72-year Magnitude	475-year Magnitude	975-year Magnitude	2,475-year Magnitude
0.01	6.37	6.59	6.69	6.79
0.02	6.37	6.59	6.69	6.79
0.03	6.36	6.58	6.67	6.77
0.04	6.35	6.58	6.66	6.75
0.05	6.34	6.55	6.64	6.72
0.075	6.30	6.51	6.59	6.67
0.1	6.28	6.50	6.57	6.64
0.15	6.30	6.53	6.63	6.70
0.2	6.34	6.58	6.69	6.78
0.25	6.39	6.64	6.75	6.85
0.3	6.44	6.69	6.80	6.89
0.4	6.53	6.79	6.88	6.97
0.5	6.58	6.84	6.93	7.02
0.75	6.70	6.94	7.02	7.09
1	6.77	7.00	7.07	7.14
1.5	6.91	7.12	7.17	7.21
2	6.98	7.19	7.23	7.25
3	7.12	7.29	7.31	7.32
4	7.18	7.37	7.37	7.38
5	7.23	7.42	7.42	7.42
7.5	7.33	7.54	7.55	7.55
10	7.36	7.58	7.60	7.61

Table 33. Mean distance for the four hazard levels for Site 8 ($V_{S30} = 450$ m/sec) without inclusion of the directivity models.

Period (sec)	72-year Distance (km)	475-year Distance (km)	975-year Distance (km)	2,475-year Distance (km)
0.01	26.57	10.54	7.84	6.11
0.02	26.46	10.40	7.78	6.10
0.03	26.29	10.35	7.96	6.25
0.04	26.02	9.95	8.11	6.46
0.05	25.63	10.53	8.16	6.72
0.075	25.91	11.28	8.75	6.89
0.1	25.46	10.89	9.07	7.27
0.15	25.92	11.44	8.63	7.24
0.2	26.75	11.63	8.44	7.04
0.25	27.82	11.87	8.45	6.91
0.3	29.03	12.14	8.60	6.91
0.4	31.69	12.47	9.53	7.05
0.5	34.64	14.31	10.18	7.14
0.75	39.45	15.74	11.01	7.64
1	41.40	17.63	11.51	7.64
1.5	47.46	20.96	13.70	8.78
2	51.86	23.00	15.51	9.93
3	57.52	26.35	17.79	11.16
4	61.32	28.60	19.95	12.90
5	63.70	32.49	23.09	15.18
7.5	71.91	42.79	35.27	27.60
10	77.85	49.44	43.10	36.69

Table 34. Mean epsilon for the four hazard levels for Site 8 ($V_{S30} = 450$ m/sec) without inclusion of the directivity models.

Period (sec)	72-year Epsilon	475-year Epsilon	975-year Epsilon	2,475-year Epsilon
0.01	0.08	0.53	0.79	1.21
0.02	0.07	0.52	0.79	1.22
0.03	0.09	0.55	0.82	1.22
0.04	0.12	0.58	0.85	1.22
0.05	0.16	0.61	0.89	1.25
0.075	0.21	0.70	0.95	1.33
0.1	0.24	0.75	0.99	1.33
0.15	0.21	0.70	0.97	1.30
0.2	0.18	0.63	0.89	1.22
0.25	0.17	0.58	0.83	1.16
0.3	0.19	0.56	0.80	1.13
0.4	0.21	0.53	0.76	1.10
0.5	0.22	0.52	0.73	1.09
0.75	0.26	0.51	0.71	1.07
1	0.26	0.48	0.67	1.04
1.5	0.23	0.47	0.65	1.02
2	0.18	0.45	0.65	1.01
3	0.10	0.43	0.63	0.99
4	0.00	0.42	0.64	1.00
5	-0.07	0.42	0.66	1.01
7.5	-0.19	0.49	0.77	1.13
10	-0.29	0.47	0.78	1.17

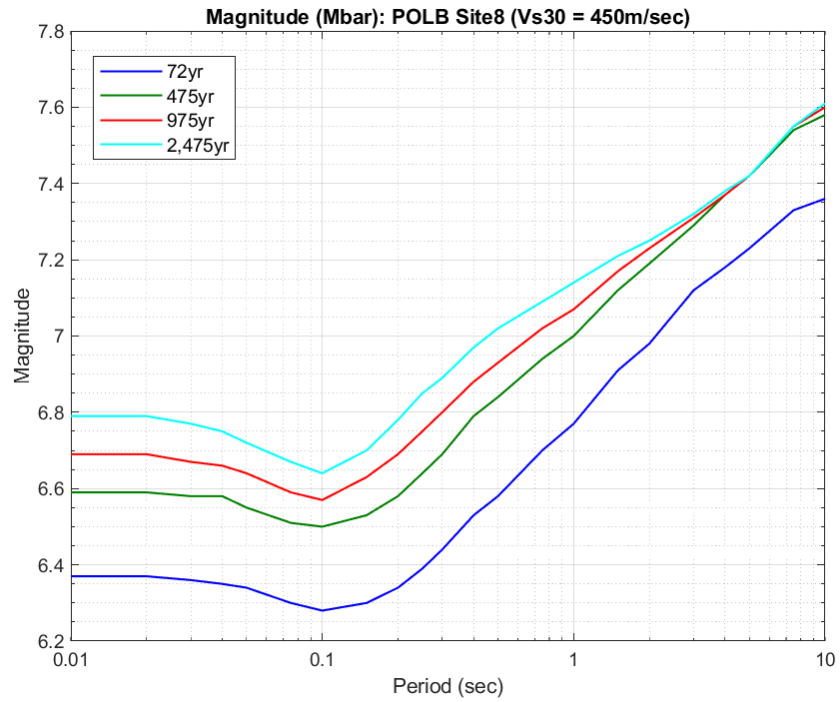


Figure 172. Horizontal mean magnitude for Site 8 ($V_{s30} = 450$ m/sec) without the inclusion of the directivity models.

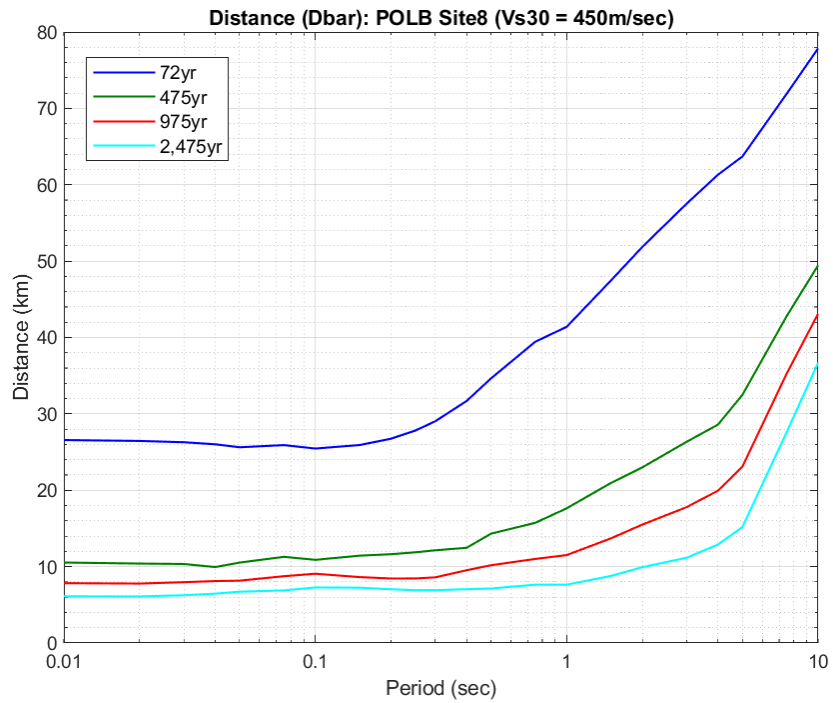


Figure 173. Horizontal mean distance for Site 8 ($V_{s30} = 450$ m/sec) without the inclusion of the directivity models.

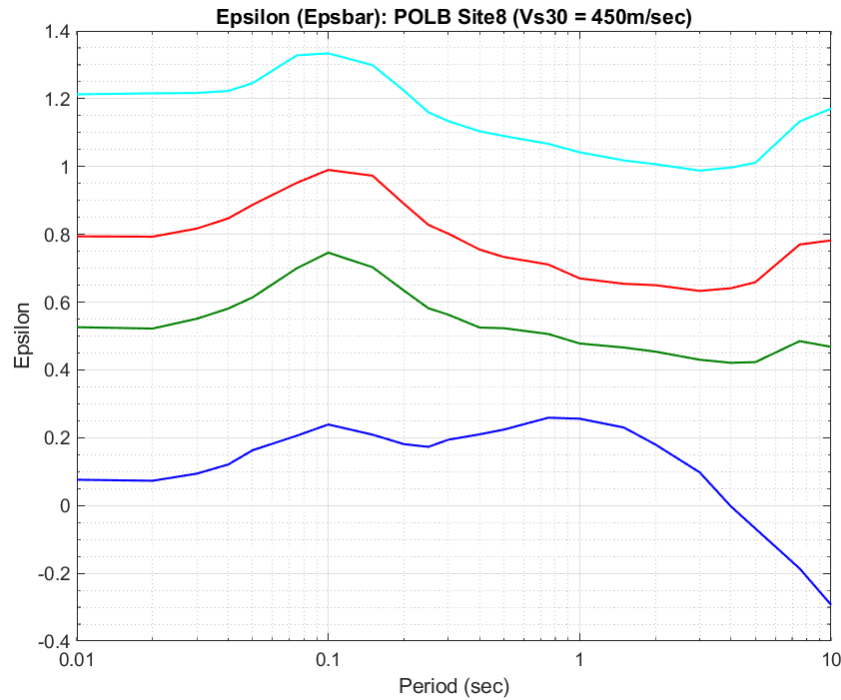


Figure 174. Horizontal mean epsilon for Site 8 ($V_{s30} = 450$ m/sec) without the inclusion of the directivity models.

The binned magnitude and distance contributions to the 72-year hazard level are shown in Figures 175 to 178 for Site 8 ($V_{s30} = 450$ m/sec) for PGA and spectral periods of 0.2, 1.0, and 3.0 sec. Similar plots are shown in Figures 179 to 182 for the 475-year hazard level, Figures 183 to 186 for the 975-year hazard level, and Figures 187 to 190 for the 2,475-year hazard level.

At the shortest return period level of 72 years, the hazard is being contributed to from small to moderate magnitude events over a broad distance of less than about 100 km. At the longer spectral periods, a relative increase in the contribution to the total hazard is observed for the larger magnitude (i.e., greater than 7.0) in the distance bin of 50 – 100 km. This corresponds to the contribution from the San Andreas and San Jacinto faults with their relatively higher slip rates. At the longer return period hazard levels, the relative increased contribution of the local faults to the total hazard is observed in the deaggregation plots with the majority of the contribution from sources with distance less than about 50 km. Based on this increased contribution from these local faults, the relative contribution from the San Andreas fault is decreased even at the longer spectral periods.

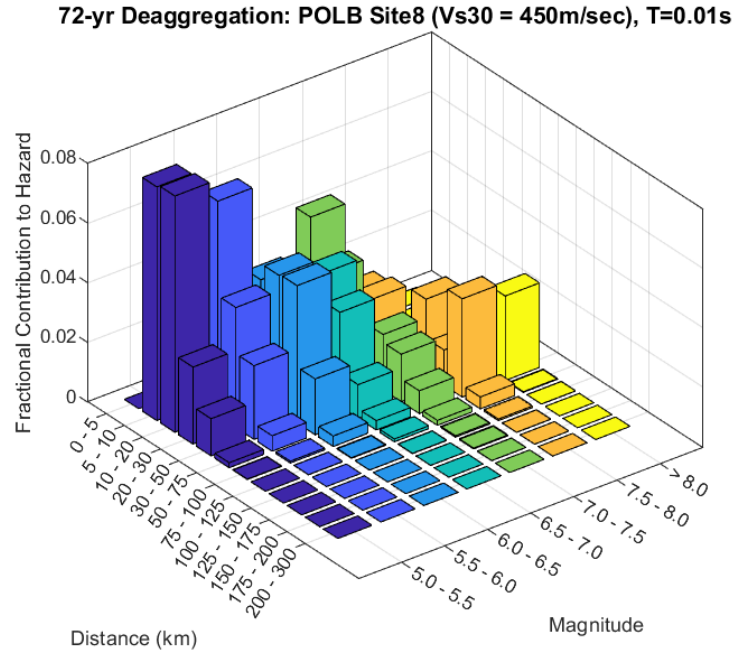


Figure 175. Magnitude-distance contribution for the 72-year hazard level for PGA for Site 8 ($V_{s30} = 450$ m/sec).

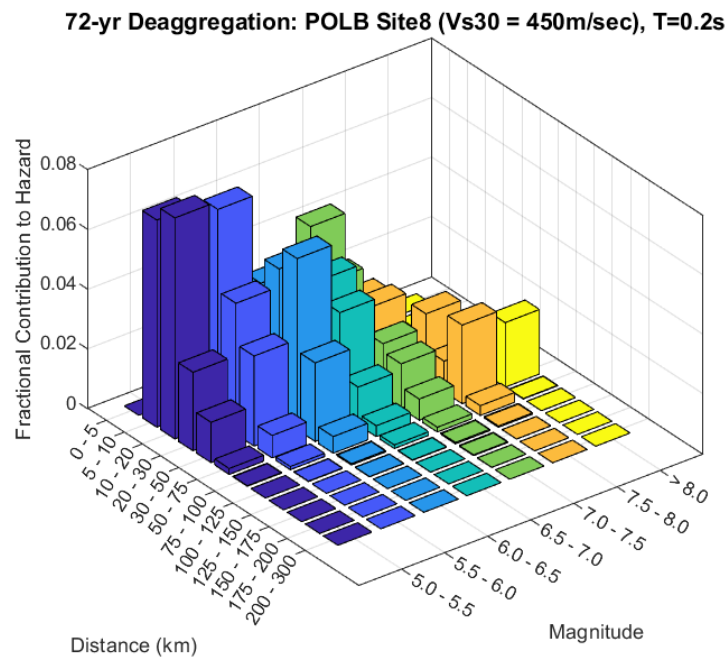


Figure 176. Magnitude-distance contribution for the 72-year hazard level for $T = 0.2$ sec for Site 8 ($V_{s30} = 450$ m/sec).

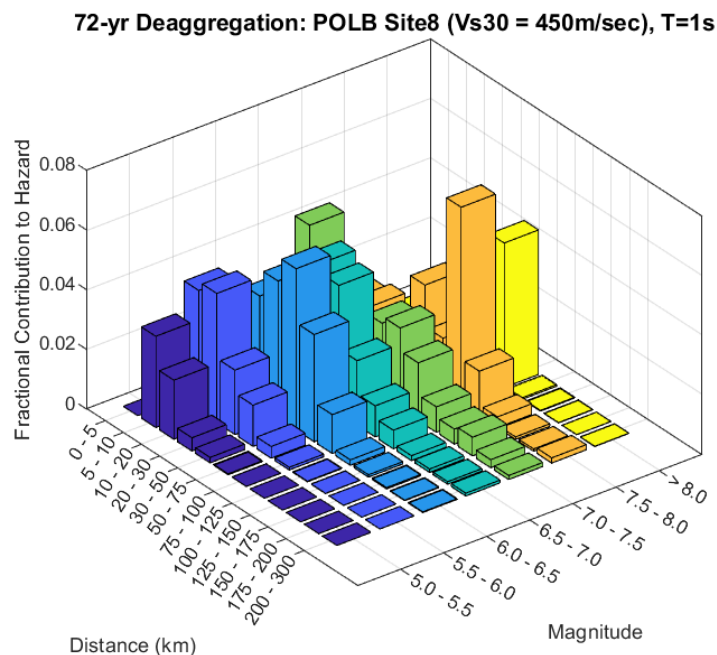


Figure 177. Magnitude-distance contribution for the 72-year hazard level for T = 1.0 sec for Site 8 ($V_{s30} = 450$ m/sec).

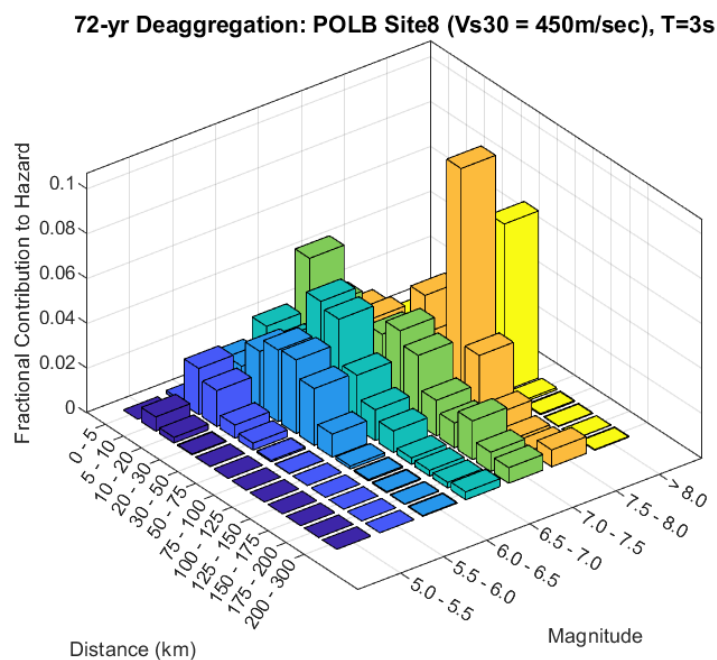


Figure 178. Magnitude-distance contribution for the 72-year hazard level for T = 3.0 sec for Site 8 ($V_{s30} = 450$ m/sec).

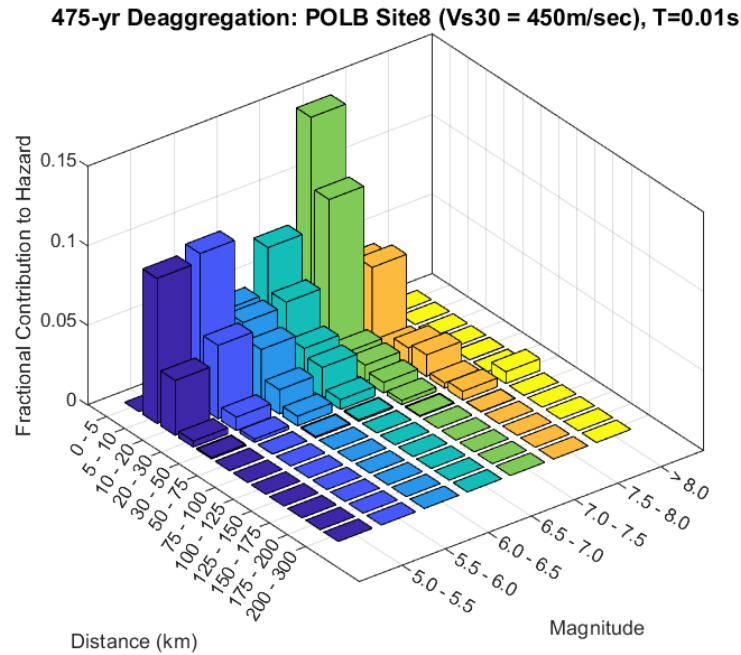


Figure 179. Magnitude-distance contribution for the 475-year hazard level for PGA for Site 8 ($V_{s30} = 450$ m/sec).

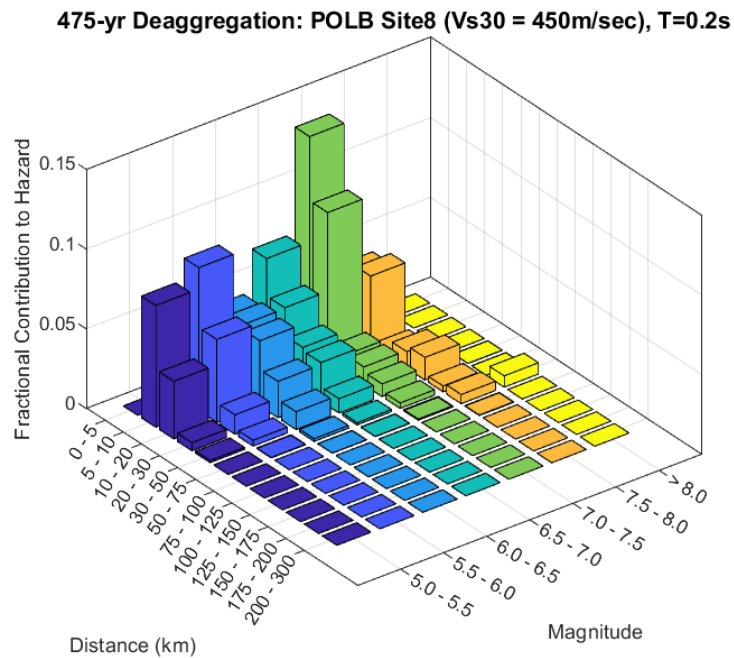


Figure 180. Magnitude-distance contribution for the 475-year hazard level for $T = 0.2$ sec for Site 8 ($V_{s30} = 450$ m/sec).

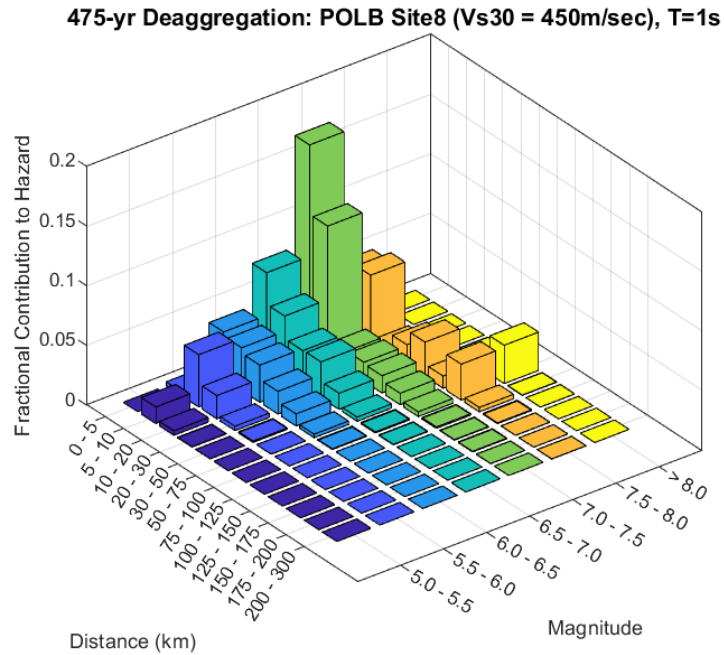


Figure 181. Magnitude-distance contribution for the 475-year hazard level for T = 1.0 sec for Site 8 ($V_{s30} = 450$ m/sec).

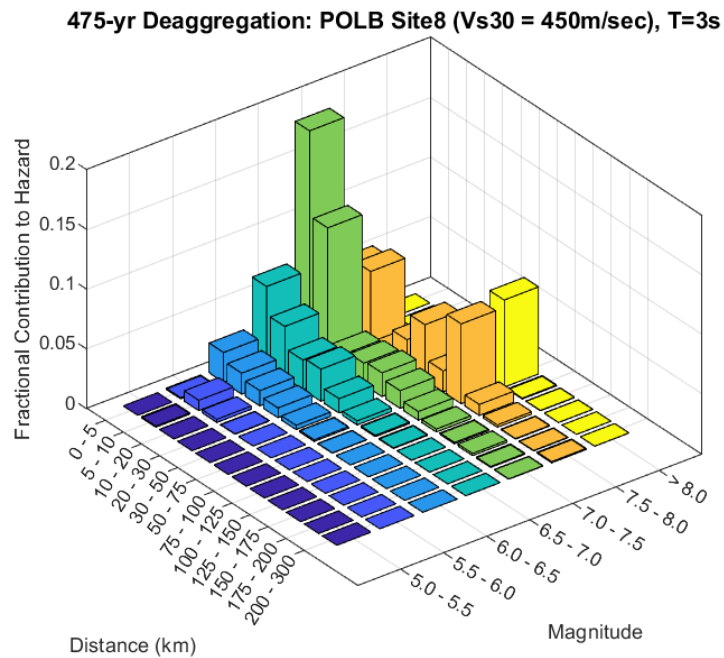


Figure 182. Magnitude-distance contribution for the 475-year hazard level for T = 3.0 sec for Site 8 ($V_{s30} = 450$ m/sec).

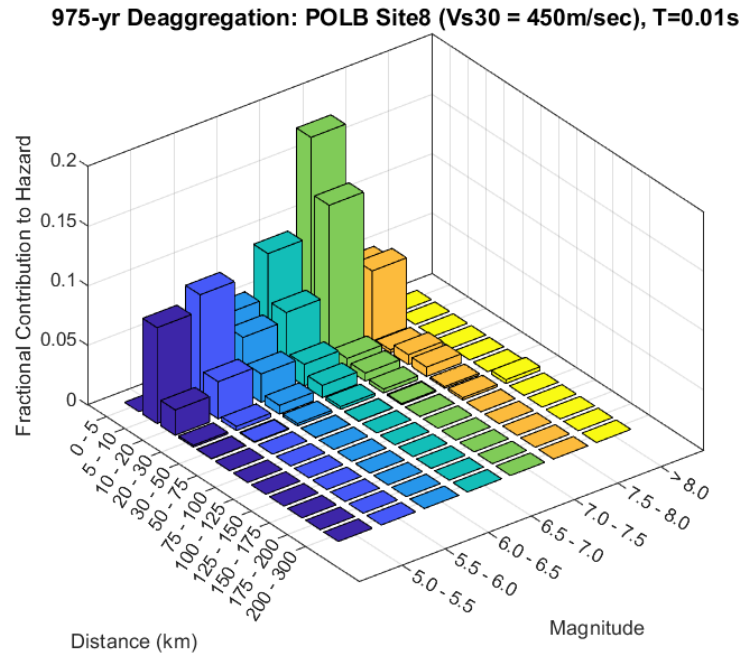


Figure 183. Magnitude-distance contribution for the 975-year hazard level for PGA for Site 8 ($V_{s30} = 450$ m/sec).

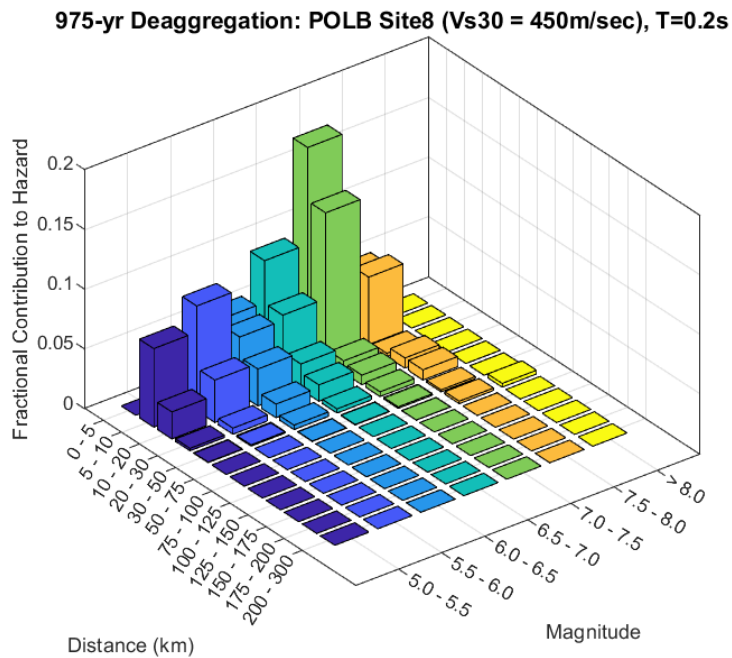


Figure 184. Magnitude-distance contribution for the 975-year hazard level for $T = 0.2$ sec for Site 8 ($V_{s30} = 450$ m/sec).

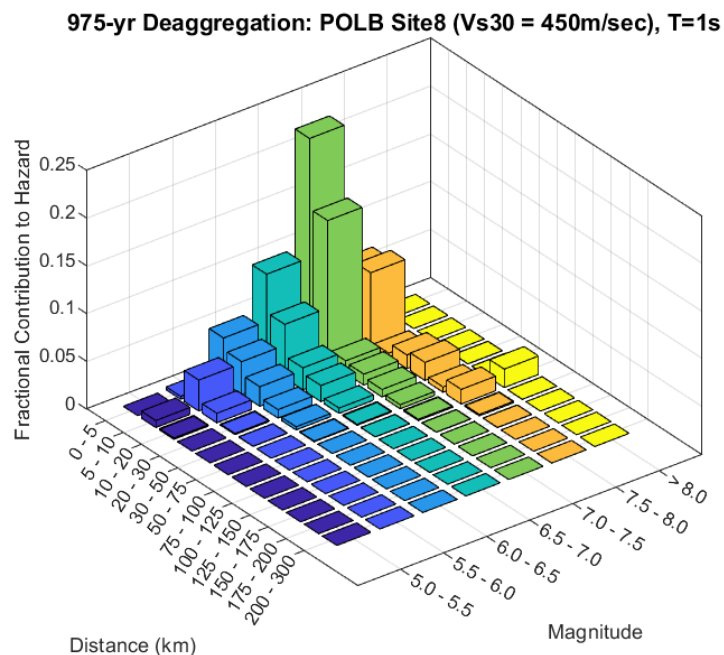


Figure 185. Magnitude-distance contribution for the 975-year hazard level for T = 1.0 sec for Site 8 ($V_{s30} = 450$ m/sec).

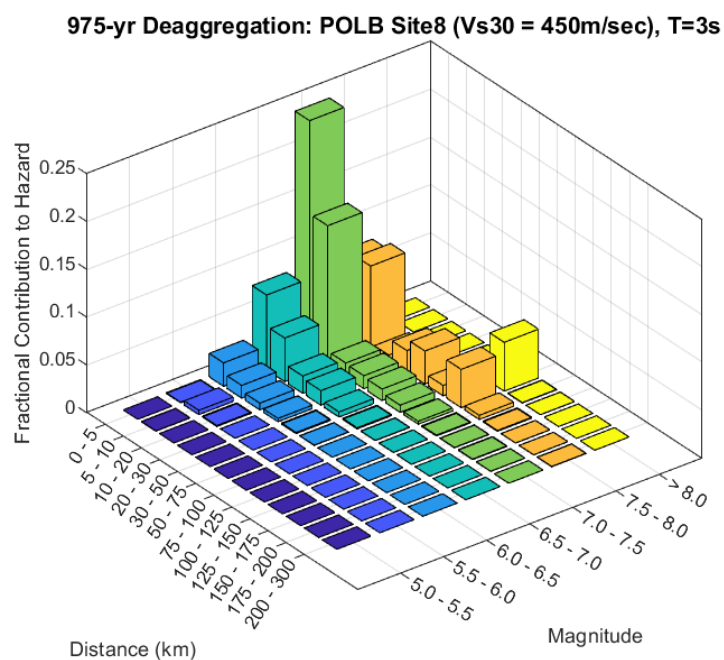


Figure 186. Magnitude-distance contribution for the 975-year hazard level for T = 3.0 sec for Site 8 ($V_{s30} = 450$ m/sec).

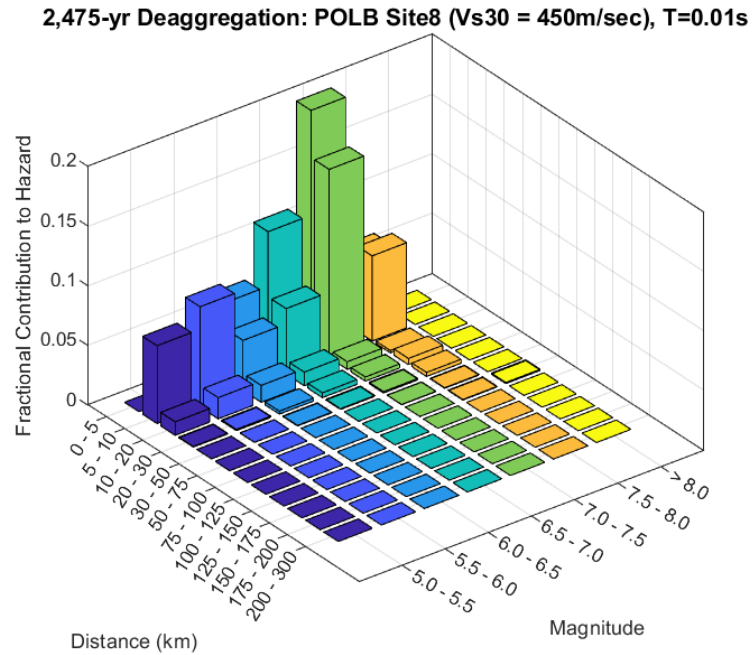


Figure 187. Magnitude-distance contribution for the 2,475-year hazard level for PGA for Site 8 ($V_{s30} = 450$ m/sec).

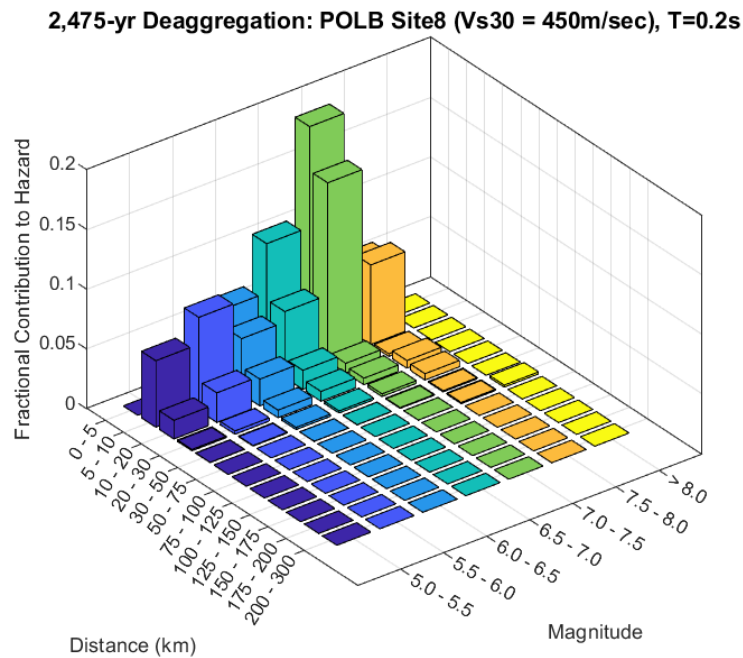


Figure 188. Magnitude-distance contribution for the 2,475-year hazard level for $T = 0.2$ sec for Site 8 ($V_{s30} = 450$ m/sec).

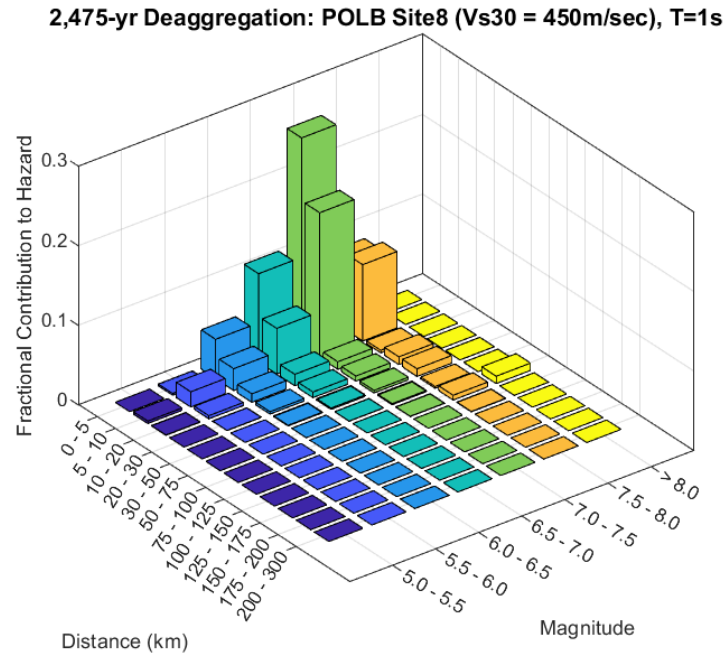


Figure 189. Magnitude-distance contribution for the 2,475-year hazard level for T = 1.0 sec for Site 8 ($V_{s30} = 450$ m/sec).

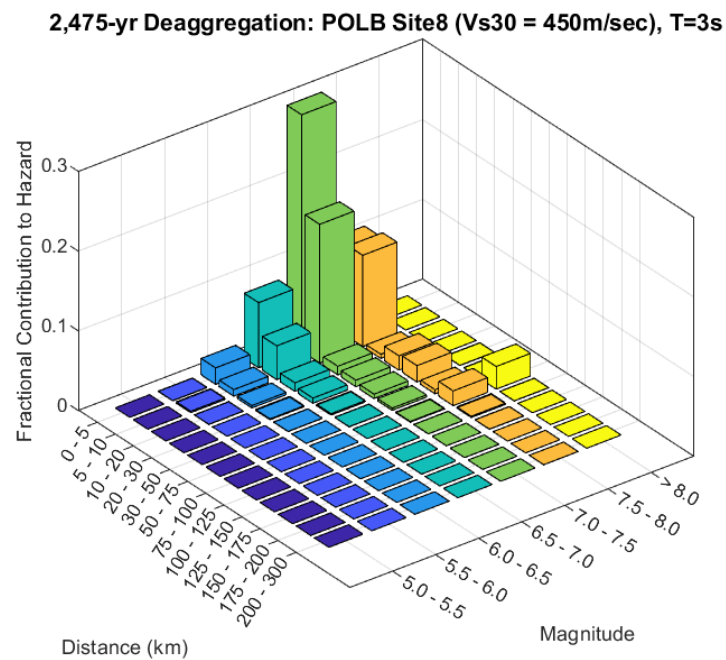


Figure 190. Magnitude-distance contribution for the 2,475-year hazard level for T = 3.0 sec for Site 8 ($V_{s30} = 450$ m/sec).

The hazard results for this site are not compared to results from the NSHM 2018 (NSHM18) and the NSHM 2023 (NSHM23). Given the proximity of the study sites, similar observations and trends are expected compared to the NSHMs results to those discussed in Section 4.2.1 for site 1.

4.5.2 Site 8 Results with Directivity, $V_{S30} = 450$ m/sec

The results for Site 8 with $V_{S30} = 450$ m/sec with the inclusion of the directivity models is presented in this section. Note that the adjustments based on the directivity models only impact the longer spectral period ground motions (i.e., periods equal to and greater than 0.5 sec) and the results presented earlier for the shorter periods are unaffected by the directivity models. The mean total hazard curves for spectral periods of 1.0, 3.0, 5.0 and 10.0 seconds are plotted in Figures 191 through 194. In each plot, the individual hazard curves for each directivity model are plotted along with the weighted mean (dashed light blue line) using the assigned weights for the suite of directivity models. For comparison the mean hazard curve without directivity is also plotted (heavy black line).

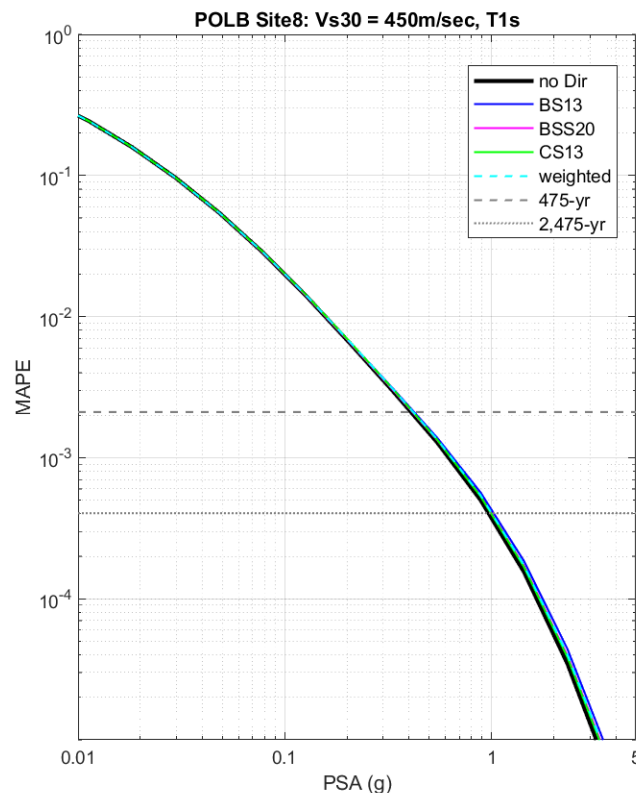


Figure 191. Total mean hazard curves without directivity (heavy black line), individual directivity models and weighted directivity results (dashed blue line) for Site 8 ($V_{S30} = 450$ m/sec) for $T=1.0$ sec spectral period. MAPE refers to mean annual probability of exceedance.

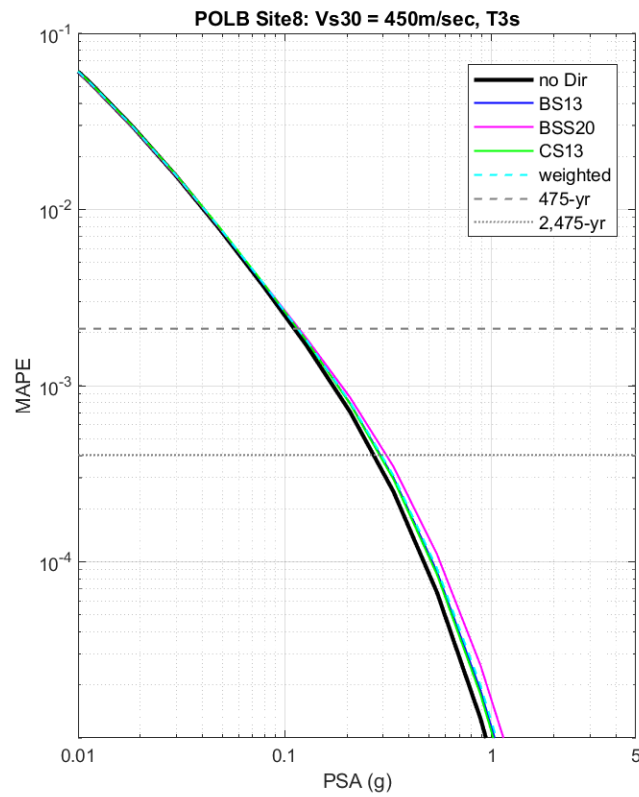


Figure 192. Total mean hazard curves without directivity (heavy black line), individual directivity models and weighted directivity results (dashed blue line) for Site 8 ($V_{s30} = 450$ m/sec) for $T=3.0$ sec spectral period. MAPE refers to mean annual probability of exceedance.

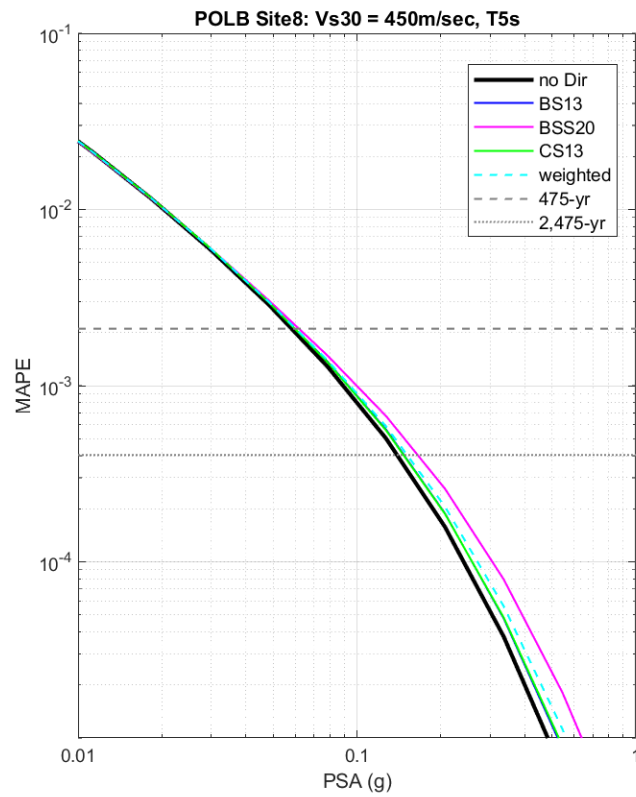


Figure 193. Total mean hazard curves without directivity (heavy black line), individual directivity models and weighted directivity results (dashed blue line) for Site 8 ($V_{S30} = 450$ m/sec) for $T=5.0$ sec spectral period. MAPE refers to mean annual probability of exceedance.

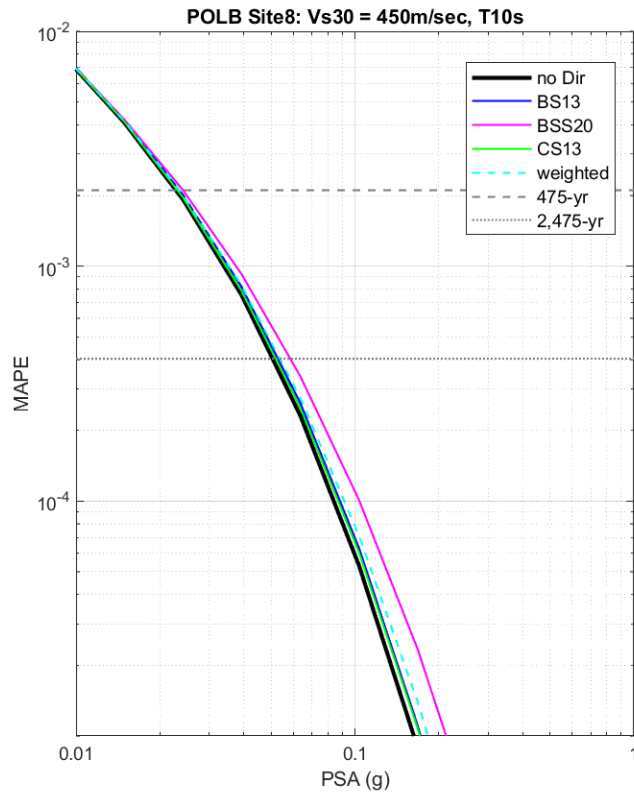


Figure 194. Total mean hazard curves without directivity (heavy black line), individual directivity models and weighted directivity results (dashed blue line) for Site 8 ($V_{s30} = 450$ m/sec) for $T=10.0$ sec spectral period. MAPE refers to mean annual probability of exceedance.

All of the directivity models show an increase in the hazard with the BSS20 model yielding the largest increase. To observe the impact on the ground motions from these directivity models, spectral ratios of the UHS ground motions are computed and plotted in Figure 195 through 198 for the selected four hazard levels. At the 72-year hazard level, there is minimal impact from the directivity models. For the longer return period levels, the results from the directivity models increase, especially for the longer spectral periods, beyond the period range of interest for this project. The UHS including the weighting combination of the directivity models for the four return period levels are listed in Table 35. The comparison of the UHS both with and without the directivity models are plotted in Figures 199 through 202 for the selected four hazard levels. Overall, the increase in the long-period ground motion due to directivity effects is observed to be 10% or less for the weighted directivity models. Similar deaggregation results are observed for the directivity cases and are not presented in the report.

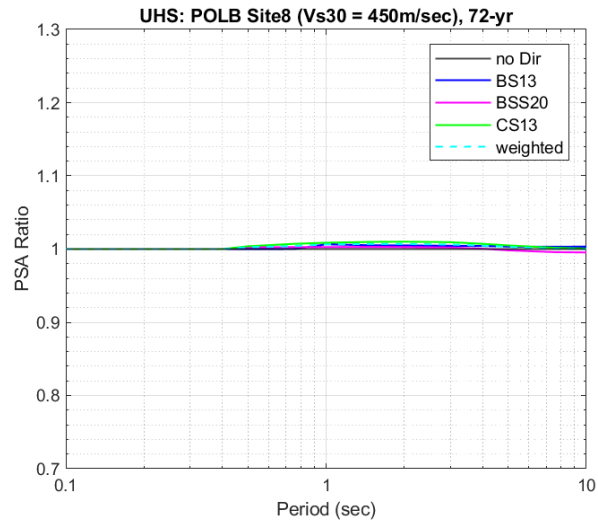


Figure 195. UHS spectral ratio for Site 8 ($V_{s30} = 450$ m/sec) for the 72-year return period hazard level for the individual and weighted combination directivity models.

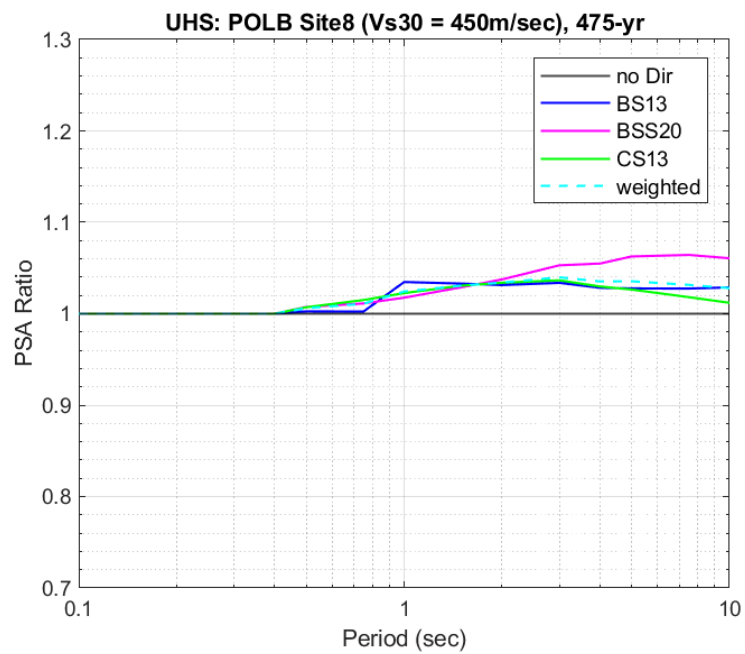


Figure 196. UHS spectral ratio for Site 8 ($V_{s30} = 450$ m/sec) for the 475-year return period hazard level for the individual and weighted combination directivity models.

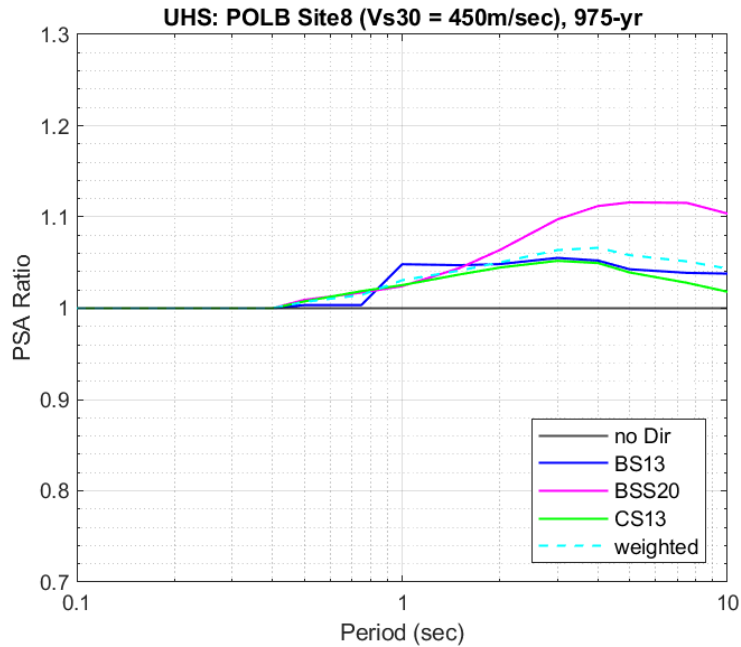


Figure 197. UHS spectral ratio for Site 8 ($V_{s30} = 450$ m/sec) for the 975-year return period hazard level for the individual and weighted combination directivity models.

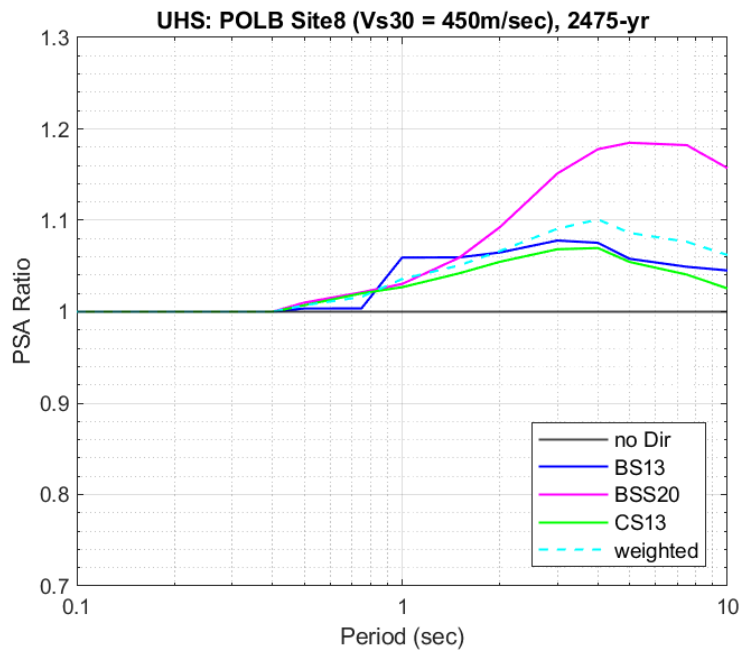


Figure 198. UHS spectral ratio for Site 8 ($V_{s30} = 450$ m/sec) for the 2,475-year return period hazard level for the individual and weighted combination directivity models.

Table 35. Horizontal UHS for Site 8 ($V_{S30} = 450$ m/sec) at the four hazard levels with the inclusion of the combined weighted directivity models.

Period (sec)	72-year Horizontal PSA (g)	475-year Horizontal PSA (g)	975-year Horizontal PSA (g)	2,475-year Horizontal PSA (g)
0.01	0.1562	0.4486	0.6220	0.8966
0.02	0.1573	0.4546	0.6302	0.9078
0.03	0.1677	0.4867	0.6708	0.9607
0.04	0.1857	0.5407	0.7406	1.0518
0.05	0.2057	0.5915	0.8216	1.1619
0.075	0.2627	0.7491	1.0306	1.4821
0.1	0.3135	0.8878	1.2040	1.7066
0.15	0.3663	1.0268	1.4224	1.9886
0.2	0.3744	1.0689	1.5017	2.1344
0.25	0.3622	1.0553	1.5020	2.1792
0.3	0.3422	1.0088	1.4495	2.1261
0.4	0.2920	0.8807	1.2615	1.8838
0.5	0.2524	0.7724	1.1203	1.7057
0.75	0.1762	0.5551	0.8248	1.2803
1	0.1290	0.4185	0.6322	1.0033
1.5	0.0796	0.2643	0.4027	0.6461
2	0.0549	0.1871	0.2867	0.4626
3	0.0326	0.1158	0.1793	0.2933
4	0.0221	0.0810	0.1258	0.2056
5	0.0159	0.0604	0.0931	0.1513
7.5	0.0089	0.0355	0.0533	0.0837
10	0.0056	0.0235	0.0349	0.0538

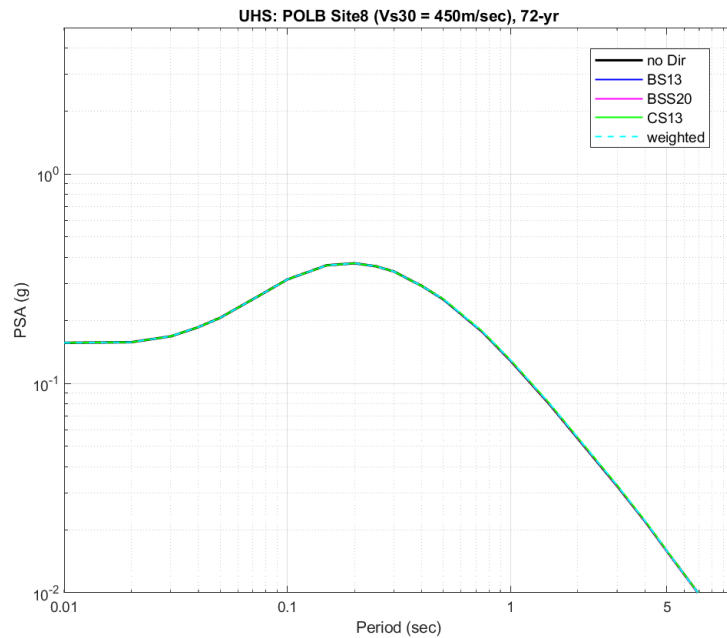


Figure 199. Uniform hazard spectra for Site 8 ($V_{S30} = 450$ m/sec) without directivity (black line) and with the individual and combined weighted (dashed blue line) directivity models for the 72-year return period.

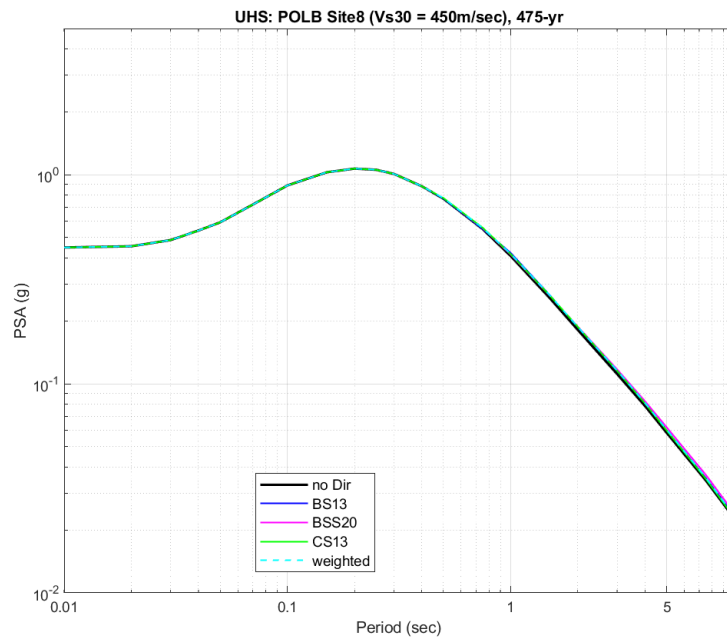


Figure 200. Uniform hazard spectra for Site 8 ($V_{S30} = 450$ m/sec) without directivity (black line) and with the individual and combined weighted (dashed blue line) directivity models for the 475-year return period.

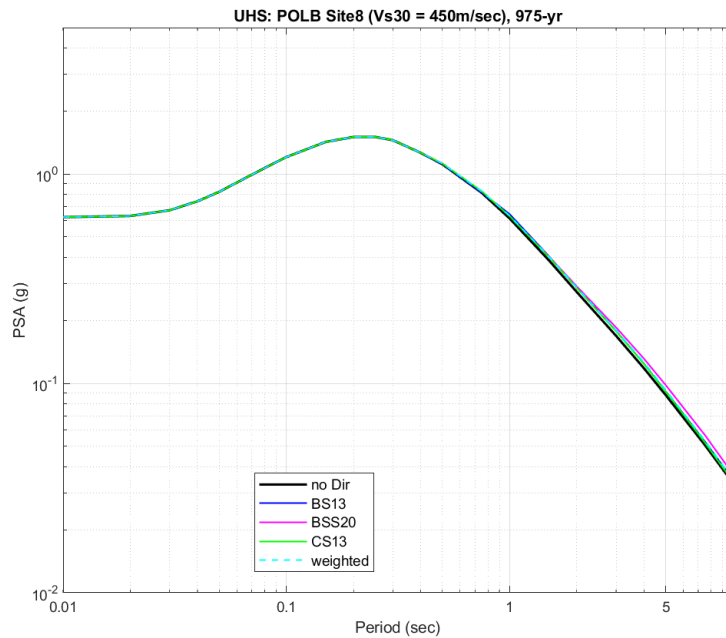


Figure 201. Uniform hazard spectra for Site 8 ($V_{S30} = 450$ m/sec) without directivity (black line) and with the individual and combined weighted (dashed blue line) directivity models for the 975-year return period.

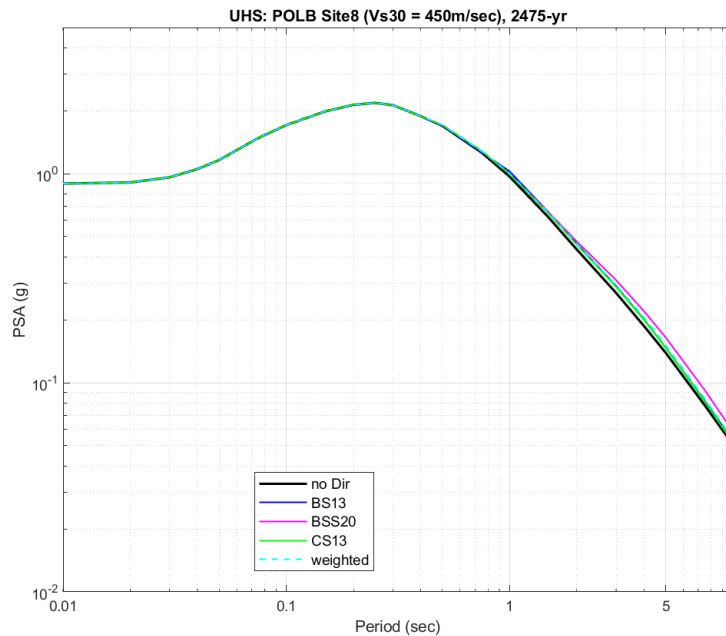


Figure 202. Uniform hazard spectra for Site 8 ($V_{S30} = 450$ m/sec) without directivity (black line) and with the individual and combined weighted (dashed blue line) directivity models for the 2,475-year return period.

Only the Bayless and Somerville (2013) directivity model is defined for the fault normal and fault parallel components of motions including directivity. The other directivity models are defined for the average horizontal component including directivity. Thus, ground motions are computed based on the application of only the Bayless and Somerville (2013) directivity model for the three cases of average horizontal, fault normal and fault parallel components. The resulting UHS for the selected four return period hazard levels are plotted in Figure 203 through 206 and listed in Table 36 through Table 38. The spectral ratio results for are plotted in Figure 207 through 210 for the selected return periods. These results show a small impact from the application of the BS13 directivity model for the 72-year hazard level. The impact, however, increases with increasing return period hazard level and as well spectral period. For the longer return period hazard levels and longer spectral periods, the fault normal results are increased by up to about 16% relative to the average horizontal component with directivity. For the fault parallel component, the ground motions are observed to approach a reduction of approximately 10% relative to the average horizontal component.

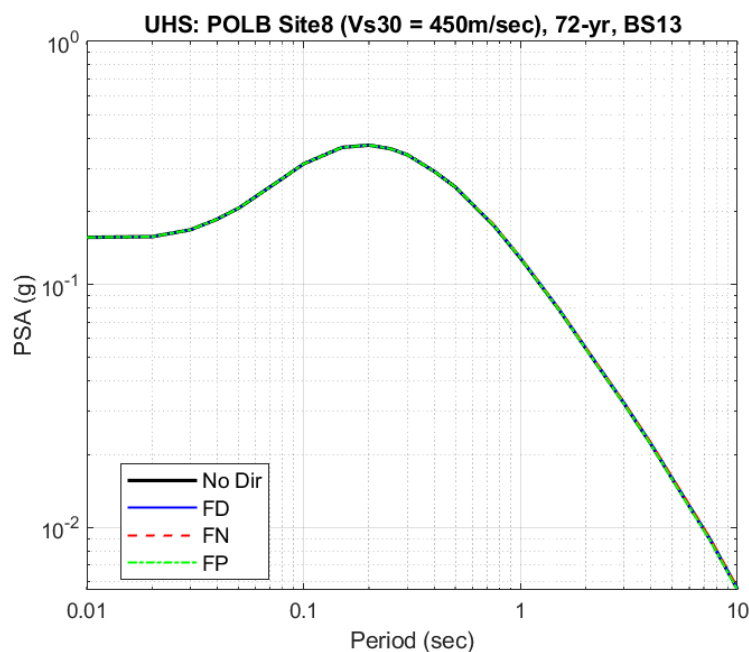


Figure 203. Uniform hazard spectra for Site 8 ($V_{s30} = 450$ m/sec) without directivity (black line) and with the BS13 directivity model for average horizontal (FD), fault normal (FN) and fault parallel (FP) components for the 72-year return period.

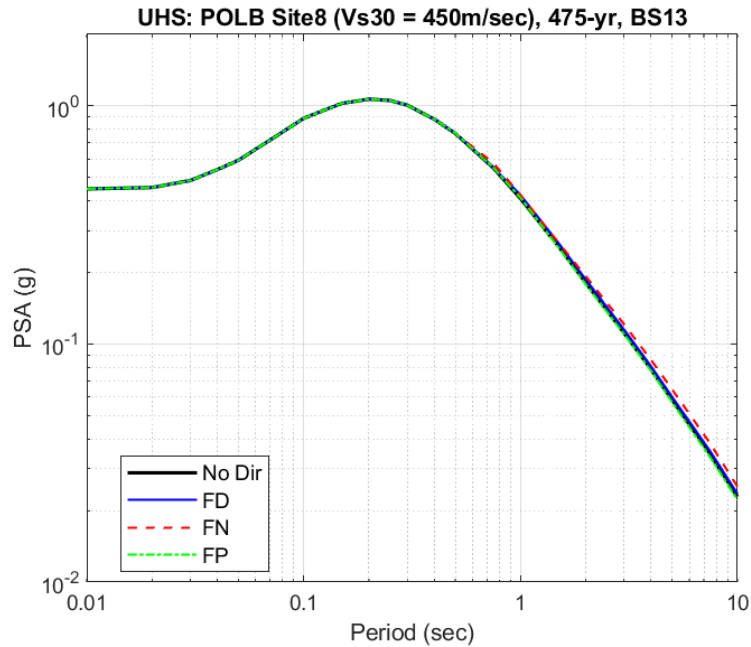


Figure 204. Uniform hazard spectra for Site 8 ($V_{s30} = 450$ m/sec) without directivity (black line) and with the BS13 directivity model for average horizontal (FD), fault normal (FN) and fault parallel (FP) components for the 475-year return period.

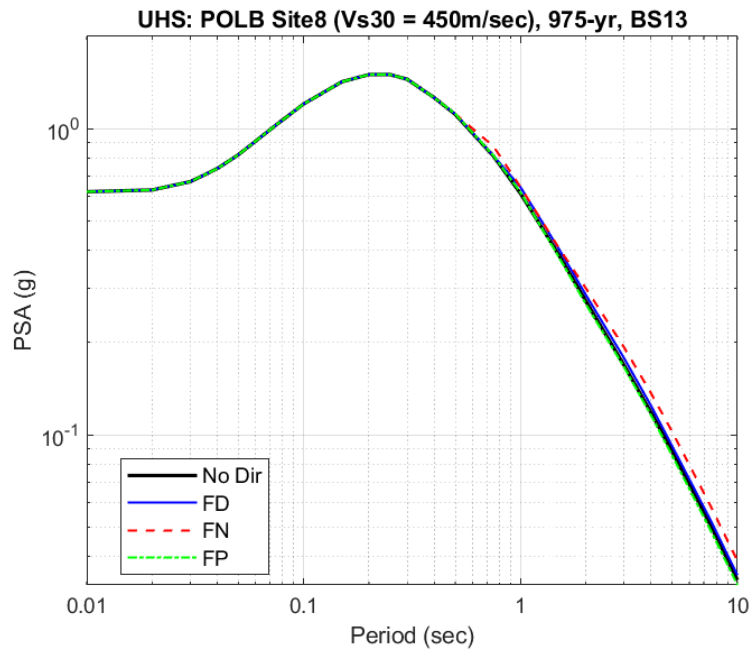


Figure 205. Uniform hazard spectra for Site 8 ($V_{s30} = 450$ m/sec) without directivity (black line) and with the BS13 directivity model for average horizontal (FD), fault normal (FN) and fault parallel (FP) components for the 975-year return period.

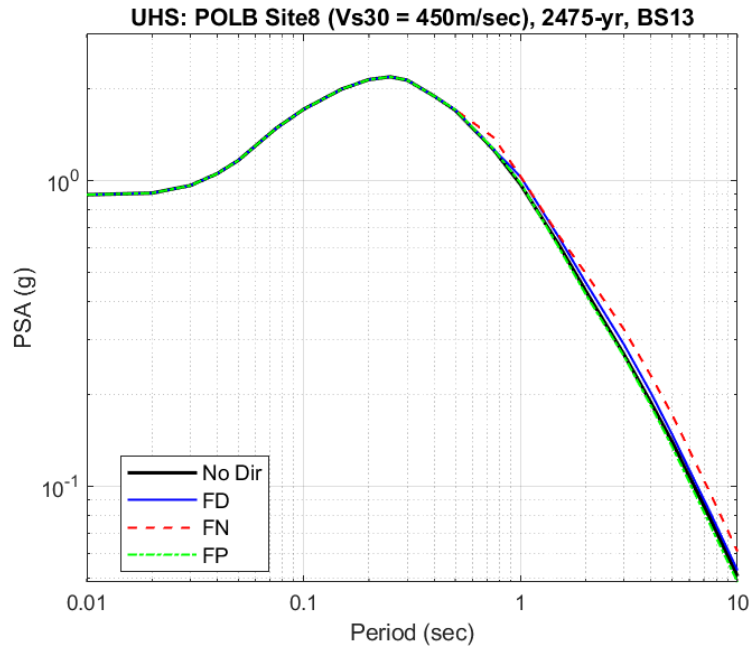


Figure 206. Uniform hazard spectra for Site 8 ($V_{s30} = 450\text{ m/sec}$) without directivity (black line) and with the BS13 directivity model for average horizontal (FD), fault normal (FN) and fault parallel (FP) components for the 2,475-year return period.

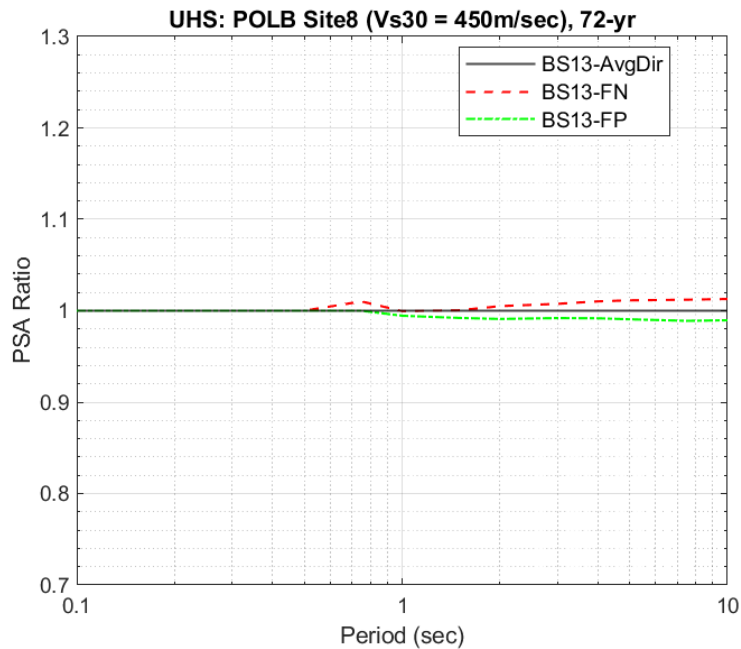


Figure 207. UHS spectral ratio for Site 8 ($V_{s30} = 450\text{ m/sec}$) for the 72-year return period hazard level for the individual horizontal components of the BS13 directivity models.

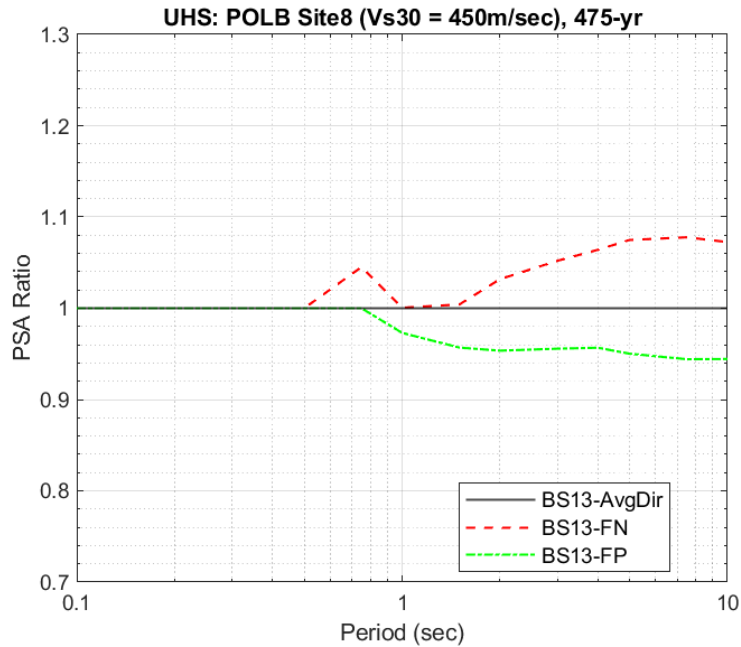


Figure 208. UHS spectral ratio for Site 8 ($V_{s30} = 450\text{ m/sec}$) for the 475-year return period hazard level for the individual horizontal components of the BS13 directivity models.

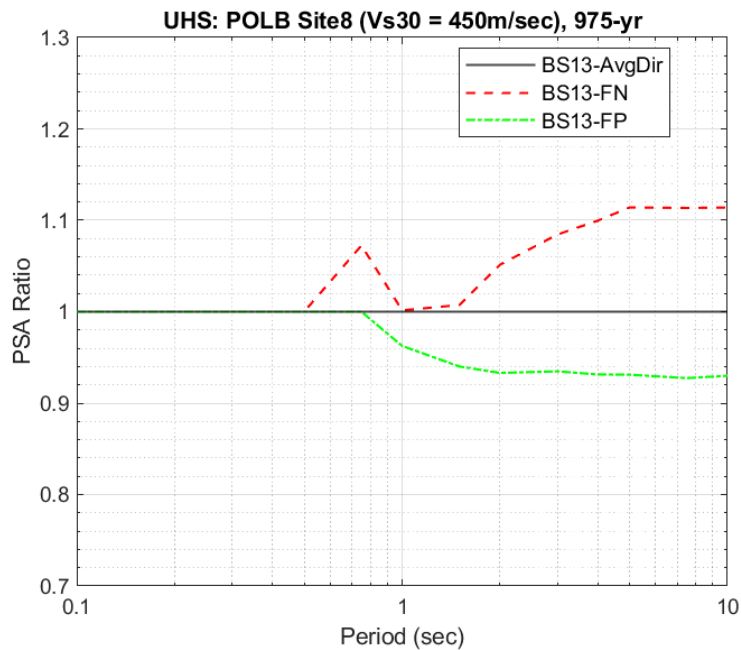


Figure 209. UHS spectral ratio for Site 8 ($V_{s30} = 450\text{ m/sec}$) for the 975-year return period hazard level for the individual horizontal components of the BS13 directivity models.

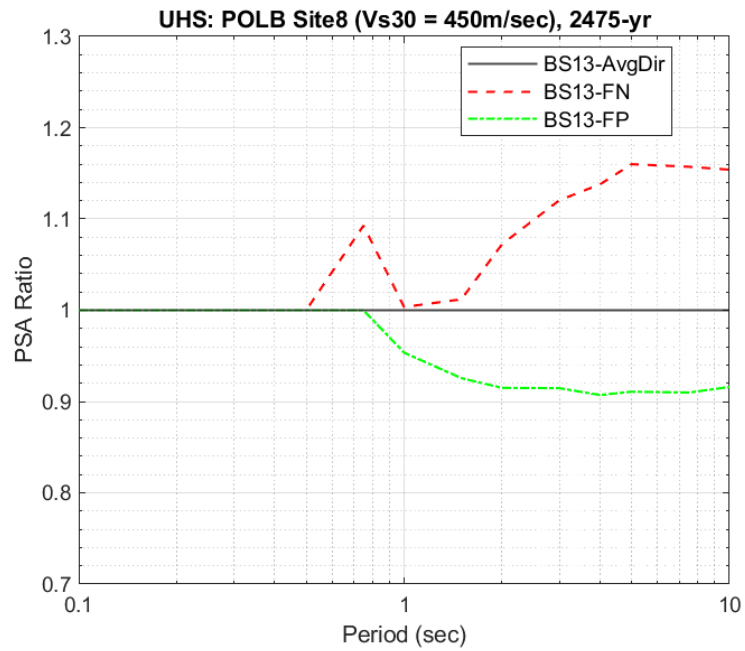


Figure 210. UHS spectral ratio for Site 8 ($V_{s30} = 450$ m/sec) for the 2,475-year return period hazard level for the individual horizontal components of the BS13 directivity models.

Table 36. Horizontal UHS for Site 8 ($V_{S30} = 450$ m/sec) at the four hazard levels with the inclusion of the BS13 directivity models for the average horizontal component.

Period (sec)	72-year Horizontal BS13 (FD) PSA (g)	475-year Horizontal BS13 (FD) PSA (g)	975-year Horizontal BS13 (FD) PSA (g)	2,475-year Horizontal BS13 (FD) PSA (g)
0.01	0.1562	0.4486	0.6220	0.8966
0.02	0.1573	0.4546	0.6302	0.9078
0.03	0.1677	0.4867	0.6708	0.9607
0.04	0.1857	0.5407	0.7406	1.0518
0.05	0.2057	0.5915	0.8216	1.1619
0.075	0.2627	0.7491	1.0306	1.4821
0.1	0.3135	0.8878	1.2040	1.7066
0.15	0.3663	1.0268	1.4224	1.9886
0.2	0.3744	1.0689	1.5017	2.1344
0.25	0.3622	1.0553	1.5020	2.1792
0.3	0.3422	1.0088	1.4495	2.1261
0.4	0.2920	0.8807	1.2615	1.8838
0.5	0.2517	0.7698	1.1165	1.6999
0.75	0.1755	0.5504	0.8158	1.2645
1	0.1290	0.4227	0.6430	1.0260
1.5	0.0795	0.2649	0.4050	0.6514
2	0.0548	0.1866	0.2862	0.4619
3	0.0325	0.1151	0.1779	0.2899
4	0.0220	0.0805	0.1241	0.2008
5	0.0159	0.0599	0.0918	0.1473
7.5	0.0089	0.0354	0.0527	0.0816
10	0.0056	0.0235	0.0347	0.0529

Table 37. Horizontal UHS for Site 8 ($V_{S30} = 450$ m/sec) at the four hazard levels with the inclusion of the BS13 directivity models for the fault normal (FN) component.

Period (sec)	72-year Horizontal BS13 (FN) PSA (g)	475-year Horizontal BS13 (FN) PSA (g)	975-year Horizontal BS13 (FN) PSA (g)	2,475-year Horizontal BS13 (FN) PSA (g)
0.01	0.1562	0.4486	0.6220	0.8966
0.02	0.1573	0.4546	0.6302	0.9078
0.03	0.1677	0.4867	0.6708	0.9607
0.04	0.1857	0.5407	0.7406	1.0518
0.05	0.2057	0.5915	0.8216	1.1619
0.075	0.2627	0.7491	1.0306	1.4821
0.1	0.3135	0.8878	1.2040	1.7066
0.15	0.3663	1.0268	1.4224	1.9886
0.2	0.3744	1.0689	1.5017	2.1344
0.25	0.3622	1.0553	1.5020	2.1792
0.3	0.3422	1.0088	1.4495	2.1261
0.4	0.2920	0.8807	1.2615	1.8838
0.5	0.2517	0.7698	1.1165	1.6999
0.75	0.1773	0.5752	0.8750	1.3817
1	0.1289	0.4229	0.6439	1.0296
1.5	0.0795	0.2660	0.4080	0.6593
2	0.0551	0.1925	0.3009	0.4953
3	0.0328	0.1211	0.1929	0.3248
4	0.0223	0.0856	0.1365	0.2285
5	0.0161	0.0644	0.1022	0.1709
7.5	0.0090	0.0381	0.0587	0.0944
10	0.0057	0.0252	0.0387	0.0611

Table 38. Horizontal UHS for Site 8 ($V_{S30} = 450$ m/sec) at the four hazard levels with the inclusion of the BS13 directivity models for the fault parallel (FP) component.

Period (sec)	72-year Horizontal BS13 (FP) PSA (g)	475-year Horizontal BS13 (FP) PSA (g)	975-year Horizontal BS13 (FP) PSA (g)	2,475-year Horizontal BS13 (FP) PSA (g)
0.01	0.1562	0.4486	0.6220	0.8966
0.02	0.1573	0.4546	0.6302	0.9078
0.03	0.1677	0.4867	0.6708	0.9607
0.04	0.1857	0.5407	0.7406	1.0518
0.05	0.2057	0.5915	0.8216	1.1619
0.075	0.2627	0.7491	1.0306	1.4821
0.1	0.3135	0.8878	1.2040	1.7066
0.15	0.3663	1.0268	1.4224	1.9886
0.2	0.3744	1.0689	1.5017	2.1344
0.25	0.3622	1.0553	1.5020	2.1792
0.3	0.3422	1.0088	1.4495	2.1261
0.4	0.2920	0.8807	1.2615	1.8838
0.5	0.2517	0.7698	1.1165	1.6999
0.75	0.1755	0.5504	0.8158	1.2645
1	0.1283	0.4113	0.6189	0.9783
1.5	0.0789	0.2535	0.3808	0.6030
2	0.0543	0.1779	0.2670	0.4226
3	0.0322	0.1100	0.1663	0.2651
4	0.0219	0.0770	0.1156	0.1821
5	0.0158	0.0569	0.0854	0.1342
7.5	0.0088	0.0334	0.0489	0.0743
10	0.0055	0.0222	0.0323	0.0485

5. Vertical to Horizontal (V/H) Ratios

A standard methodology for the development of the vertical spectra through the application of vertical to horizontal (V/H) spectral ratios is recommended for the project. The process follows the selection of representative scenario events consistent with the horizontal hazard deaggregation results. Given the close location of the four sites and the consistent contribution and controlling seismic sources to the total hazard at each site being similar, it is expected that the same scenario events can be appropriate for all four site locations. Scenarios can be expected to vary across the four different hazard levels given the relative contribution to the horizontal hazard from the different seismic sources.

Given these selected scenario events, vertical to horizontal spectral ratio (V/H) values are estimated based on the empirical V/H model from Gulerce and Abrahamson (2011) and Bozorgnia and Campbell (2016). The results from these two models are assigned equal weights of 50% each. All of the calculations are computed using the same assigned V_{s30} value of 450 m/sec and the Z_1 and Z_{25} parameter values used in the PSHA.

In general, the deaggregation results for the 72-year hazard levels show a wide contribution from small to moderate magnitude events at distances less than 100 km. For the longer spectral periods, the relative contribution from larger magnitude events in the distance range of 50 – 100 km is observed. These contributions would be associated with the San Andreas fault. Based on the deaggregation results, three scenario events are selected. The earthquake parameters associated with these three scenario events are listed in Table 39. The V/H ratios from the three scenario events and the resulting envelop V/H ratios are listed in Table 40 and plotted in Figure 211 for the 72-year hazard level.

Table 39. Scenario events and associated parameters for the 72-year hazard level.

Parameter	Scenario #1	Scenario #2	Scenario #3
Magnitude	6.0	7.25	7.75
Distance [Rrup] (km)	20.0	15.0	85.0
Mechanism	Strike-slip	Strike-slip	Strike-slip
Z_{tor} (km)	2.26	0.0	0.0
Dip	90	90	90
V_{s30} (m/sec)	450.0	450.0	450.0
Z_1 (km)	0.300	0.300	0.300
Z_{25} (km)	1.105	1.105	1.105
Parent Fault	Palo Verdes	Palo Verdes	San Andreas

Table 40. Summary of V/H values from the three scenario events and the envelop V/H values for the 72-year hazard level.

Period (sec)	Scenario #1 V/H	Scenario #2 V/H	Scenario #3 V/H	Envelop V/H [72-year]
0.01	0.6131	0.6763	0.4893	0.6763
0.02	0.6269	0.6937	0.4930	0.6937
0.03	0.6876	0.7752	0.5191	0.7752
0.04	0.7412	0.8580	0.5360	0.8580
0.05	0.7856	0.9282	0.5496	0.9282
0.075	0.7774	0.9248	0.5687	0.9248
0.1	0.6774	0.8164	0.5555	0.8164
0.15	0.5567	0.6514	0.5373	0.6514
0.2	0.4899	0.5532	0.5225	0.5532
0.25	0.4503	0.4806	0.4679	0.4806
0.3	0.4215	0.4383	0.4487	0.4487
0.4	0.4025	0.3912	0.4291	0.4291
0.5	0.3925	0.3668	0.4260	0.4260
0.75	0.4261	0.3879	0.4442	0.4442
1	0.4525	0.4129	0.4808	0.4808
1.5	0.4789	0.4346	0.4727	0.4789
2	0.5189	0.4584	0.4688	0.5189
3	0.5413	0.4903	0.4948	0.5413
4	0.5460	0.5037	0.5180	0.5460
5	0.5250	0.4872	0.5276	0.5276
7.5	0.4823	0.4369	0.5002	0.5002
10	0.4481	0.4067	0.4856	0.4856

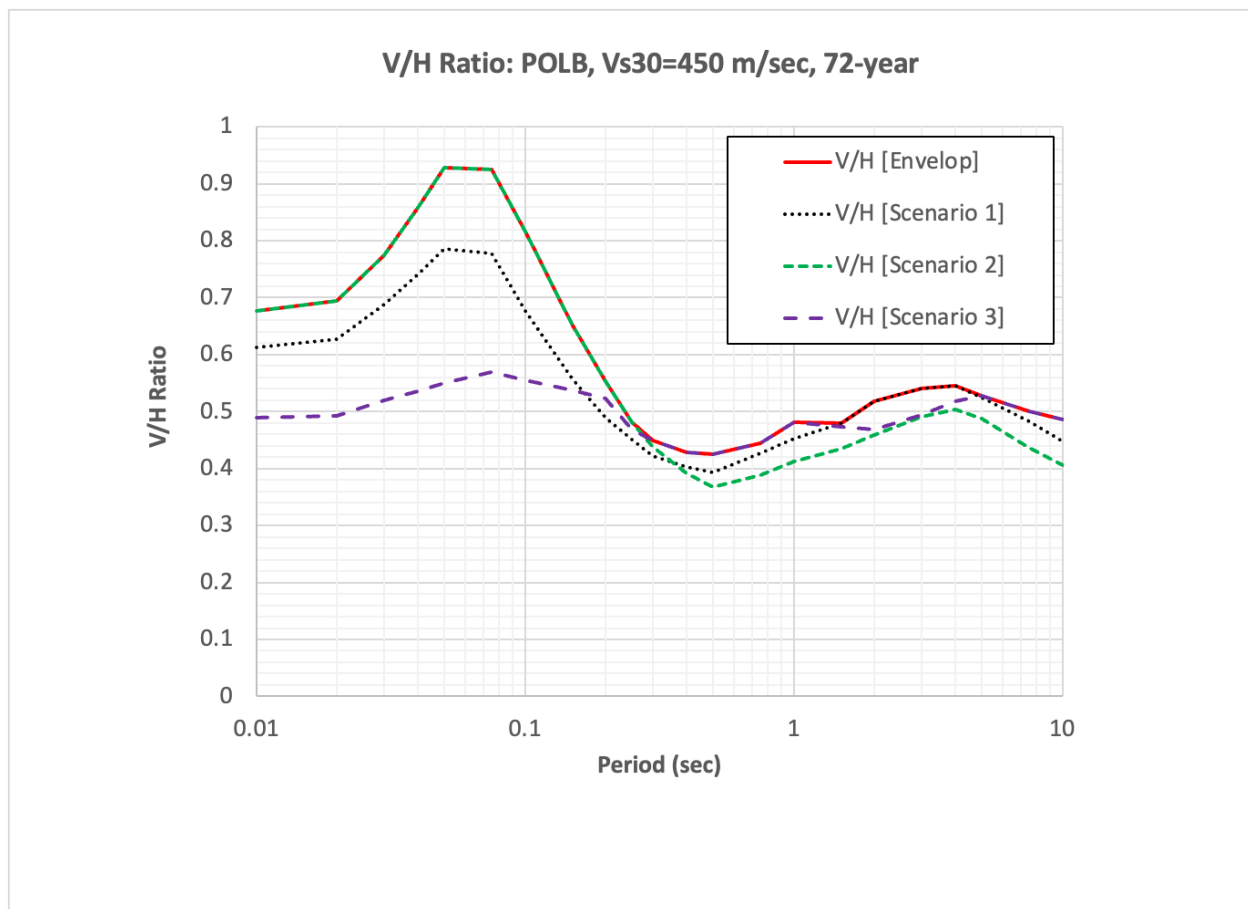


Figure 211. V/H spectra ratios for the three scenario events and envelop case for the 72-year hazard level.

The deaggregation results for both the 475 and 975-year hazard levels are similar and are observed to have slightly closer distances for the controlling scenario events than for 72-year deaggregation results. Based on these results three scenario events are also selected for these two hazard levels. For the first two scenario events, the magnitudes are the same as the 72-year case but the distances are slightly closer. The contribution from the San Andreas fault is consistent between the three hazard levels and the scenario parameters for that source is the same. The three scenarios and associated parameters are listed in Table 41. The individual V/H ratios and the resulting envelop V/H ratios are listed in Table 42 and plotted in Figure 212.

Table 41. Scenario events and associated parameters for the 475 and 975-year hazard levels.

Parameter	Scenario #1	Scenario #2	Scenario #3
Magnitude	6.0	7.25	7.75
Distance [Rrup] (km)	5.0	15.0	85.0

Mechanism	Strike-slip	Strike-slip	Strike-slip
Z _{tor} (km)	2.26	0.0	0.0
Dip	90	90	90
V _{S30} (m/sec)	450.0	450.0	450.0
Z ₁ (km)	0.300	0.300	0.300
Z ₂₅ (km)	1.105	1.105	1.105
Parent Fault	Palo Verdes	Palo Verdes	San Andreas

Table 42. Summary of V/H values from the three scenario events and the envelop V/H values for the 475 and 975-year hazard level.

Period (sec)	Scenario #1 V/H	Scenario #2 V/H	Scenario #3 V/H	Envelop V/H [475 and 975-year]
0.01	0.7409	0.7908	0.4893	0.7908
0.02	0.7661	0.8176	0.4930	0.8176
0.03	0.8552	0.9261	0.5191	0.9261
0.04	0.9367	1.0395	0.5360	1.0395
0.05	1.0053	1.1368	0.5496	1.1368
0.075	0.9871	1.1315	0.5687	1.1315
0.1	0.8381	0.9791	0.5555	0.9791
0.15	0.6665	0.7567	0.5373	0.7567
0.2	0.5484	0.6091	0.5225	0.6091
0.25	0.4737	0.5045	0.4679	0.5045
0.3	0.4289	0.4477	0.4487	0.4487
0.4	0.3927	0.3845	0.4291	0.4291
0.5	0.3731	0.3514	0.4260	0.4260
0.75	0.3999	0.3683	0.4442	0.4442
1	0.4170	0.3862	0.4808	0.4808
1.5	0.4475	0.4147	0.4727	0.4727
2	0.4774	0.4355	0.4688	0.4774
3	0.4846	0.4577	0.4948	0.4948
4	0.4883	0.4680	0.5180	0.5180
5	0.4922	0.4698	0.5276	0.5276
7.5	0.4767	0.4388	0.5002	0.5002
10	0.4409	0.4027	0.4856	0.4856

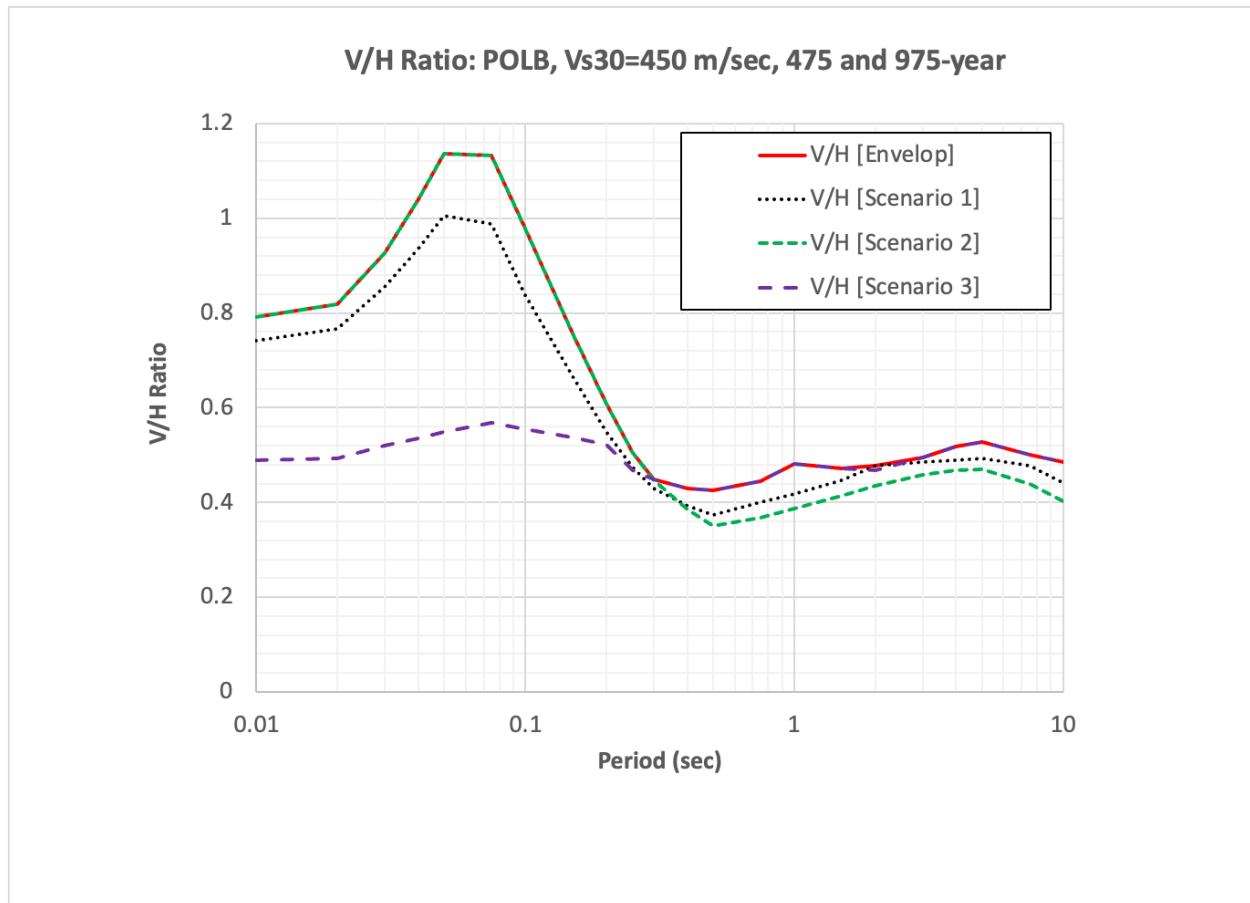


Figure 212. V/H spectra ratios for the three scenario events and envelop case for the 475 and 975-year hazard level.

The main difference observed with the deaggregation results for the 2,475-year hazard level is the lack of contribution from the more distant San Andreas fault even at the longer spectral periods. Based on this, only two scenario events are selected for the 2,475-year hazard level. These two events are the same closer scenario events selected for the 475 and 975-year hazard level case and represent the contribution from the Palos Verdes fault. The scenario parameters are listed in Table 43. Table 44 provides the individual V/H ratios and the resulting envelop V/H ratios. These results are also plotted in Figure 213.

Table 43. Scenario events and associated parameters for the 2,475-year hazard level.

Parameter	Scenario #1	Scenario #2
Magnitude	6.0	7.25
Distance [Rrup] (km)	5.0	15.0

Mechanism	Strike-slip	Strike-slip
Z _{tor} (km)	2.26	0.0
Dip	90	90
V _{S30} (m/sec)	450.0	450.0
Z ₁ (km)	0.300	0.300
Z ₂₅ (km)	1.105	1.105
Parent Fault	Palo Verdes	Palo Verdes

Table 44. Summary of V/H values from the three scenario events and the envelop V/H values for the 2,475-year hazard level.

Period (sec)	Scenario #1 V/H	Scenario #2 V/H	Envelop V/H [2,475-year]
0.01	0.7409	0.7908	0.7908
0.02	0.7661	0.8176	0.8176
0.03	0.8552	0.9261	0.9261
0.04	0.9367	1.0395	1.0395
0.05	1.0053	1.1368	1.1368
0.075	0.9871	1.1315	1.1315
0.1	0.8381	0.9791	0.9791
0.15	0.6665	0.7567	0.7567
0.2	0.5484	0.6091	0.6091
0.25	0.4737	0.5045	0.5045
0.3	0.4289	0.4477	0.4477
0.4	0.3927	0.3845	0.3927
0.5	0.3731	0.3514	0.3731
0.75	0.3999	0.3683	0.3999
1	0.4170	0.3862	0.4170
1.5	0.4475	0.4147	0.4475
2	0.4774	0.4355	0.4774
3	0.4846	0.4577	0.4846
4	0.4883	0.4680	0.4883
5	0.4922	0.4698	0.4922
7.5	0.4767	0.4388	0.4767
10	0.4409	0.4027	0.4409

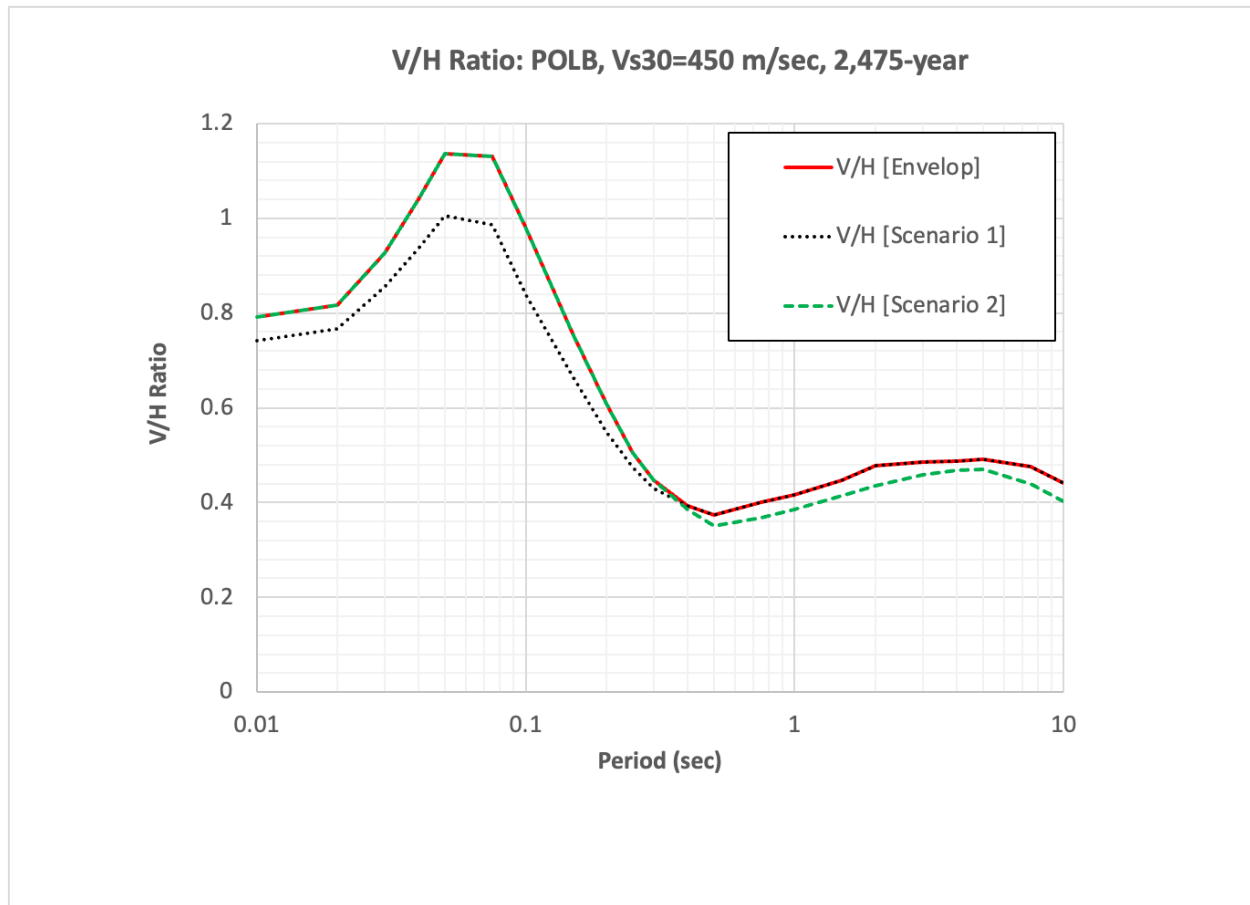


Figure 213. V/H spectra ratios for the two scenario events and envelop case for the 2,475-year hazard level.

6. Summary

An updated PSHA study is performed for sites 1, 3, 5, and 8 in the POLB area. This PSHA study implements the current state of knowledge and practice seismic source characterization model for California. More recently a newly characterized fault source (i.e., Wilmington fault) in the immediate region around POLB was developed (Wolfe et al., 2019, 2022) and its characterization is also included in this study. The results show that the Wilmington fault is not the most significant contributing seismic source to the hazard and only contributes a minor amount to the total hazard depending on the hazard level of interest.

The current study implements the current state of knowledge for ground motion characterization models (NGA West2). A common V_{S30} value of 450 m/sec is assigned for all of the calculations based on the seismic provisions presented in ASCE 7-22 (ASCE, 2022). These results are expected to be used for the evaluation of the 1D site response analyses conducted as a separate study. For the horizontal component, ground motions are computed both with and without directivity. For the directivity cases, a suite of directivity models is implemented with the final recommended results based on a weighted average of three selected models.

For the estimation of vertical ground motions, a standard methodology of applying vertical to horizontal (V/H) spectral ratios is recommended. Given the close proximity of the four sites, the same scenario earthquakes are applicable for each site for a given return period. Empirical V/H models are implemented along with the parameters from the scenario events to estimate the V/H ratio. All of the calculations are computed for the assigned V_{S30} value of 450 m/sec and the Z_1 and Z_{25} parameter values used in the PSHA. The final recommended V/H ratio consists of the envelop of the individual V/H ratios from each scenario across the full spectral period range. These V/H values are recommended to be applied to the horizontal UHS without directivity to estimate the vertical ground motions.

The mean hazard curves for selected spectral periods without the inclusion of directivity are provided electronically to allow for the risk coefficient calculation as described in ASCE 7-22.

7. References

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**APPENDIX B SPECTRUM-MATCHED GROUND MOTION TIME HISTORIES FOR
REFERENCE BEDROCK FOR MCER EVENT**

The seven (7) sets of 2-component time histories listed below in Table B1 are modified to match the reference bedrock (Site Class C) response spectrum for MCE_R using the time-domain approach. Each set has two (2) components (FN, FP), resulting in a total of 14 time histories for each ground motion level. For each time history, the following is plotted:

- ❖ Initial acceleration, velocity and displacement time histories scaled to PGA,
- ❖ Modified (spectral-matched) acceleration, velocity and displacement time histories, and
- ❖ Comparison of the target acceleration and relative displacement spectra with the spectra of the initial and the modified time histories.

These plots are shown in Figure B1 through Figure B14 for the MCE_R ground motion level.

**Table B1. SELECTED STARTUP MOTIONS FOR A 2475-YR RETURN PERIOD
EARTHQUAKE**

Set	PEER RSN *	Earthquake	Mw	Pulse Motion	Station	Distance, R_{rup} (km)
1	1787	1999 Hector Mine	7.1	No	Hector	11.7
2	767	1989 Loma Prieta	6.9	Yes	Gilroy Array 0#3	12.8
3	2114	2002 Denali, Alaska	7.9	Yes	TAPS Pump Station #10	2.7
4	1612	1999 Duzce, Turkey	7.1	No	Lamont 1059	4.2
5	6906	2010 Darfield, New Zealand	7.0	Yes	GDLC	1.2
6	6	1940 Imperial Valley	6.9	No	El Centro	6.1
7	1108	1995 Kobe, Japan	6.9	No	Kobe University	0.9

* PEER ground motion database (<https://ngawest2.berkeley.edu/>).

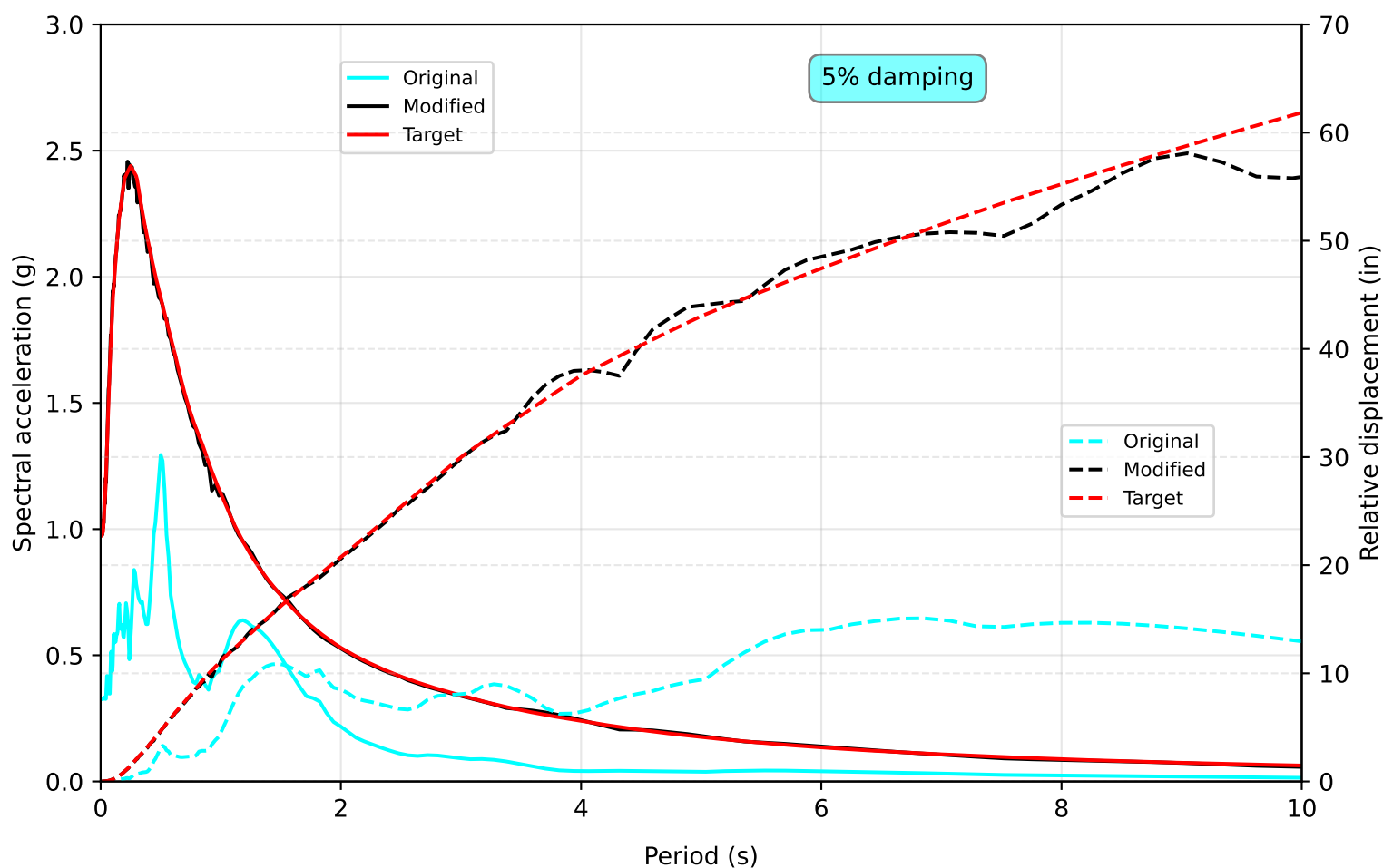
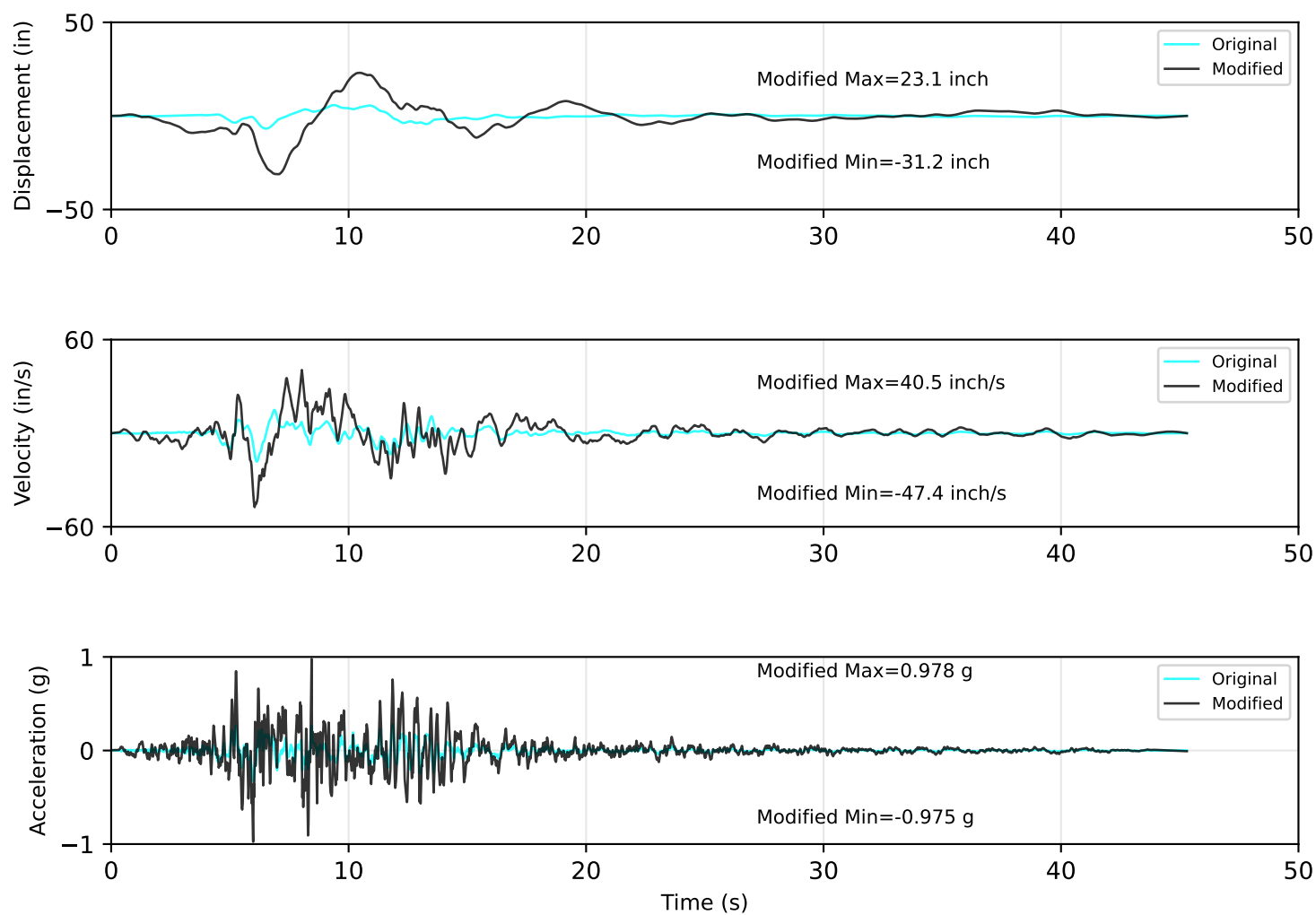


Figure B1. Reference Bedrock (Site Class C) ASCE 7-22 MCER Spectrum-matched Ground Motion - Set-1-Fault Normal

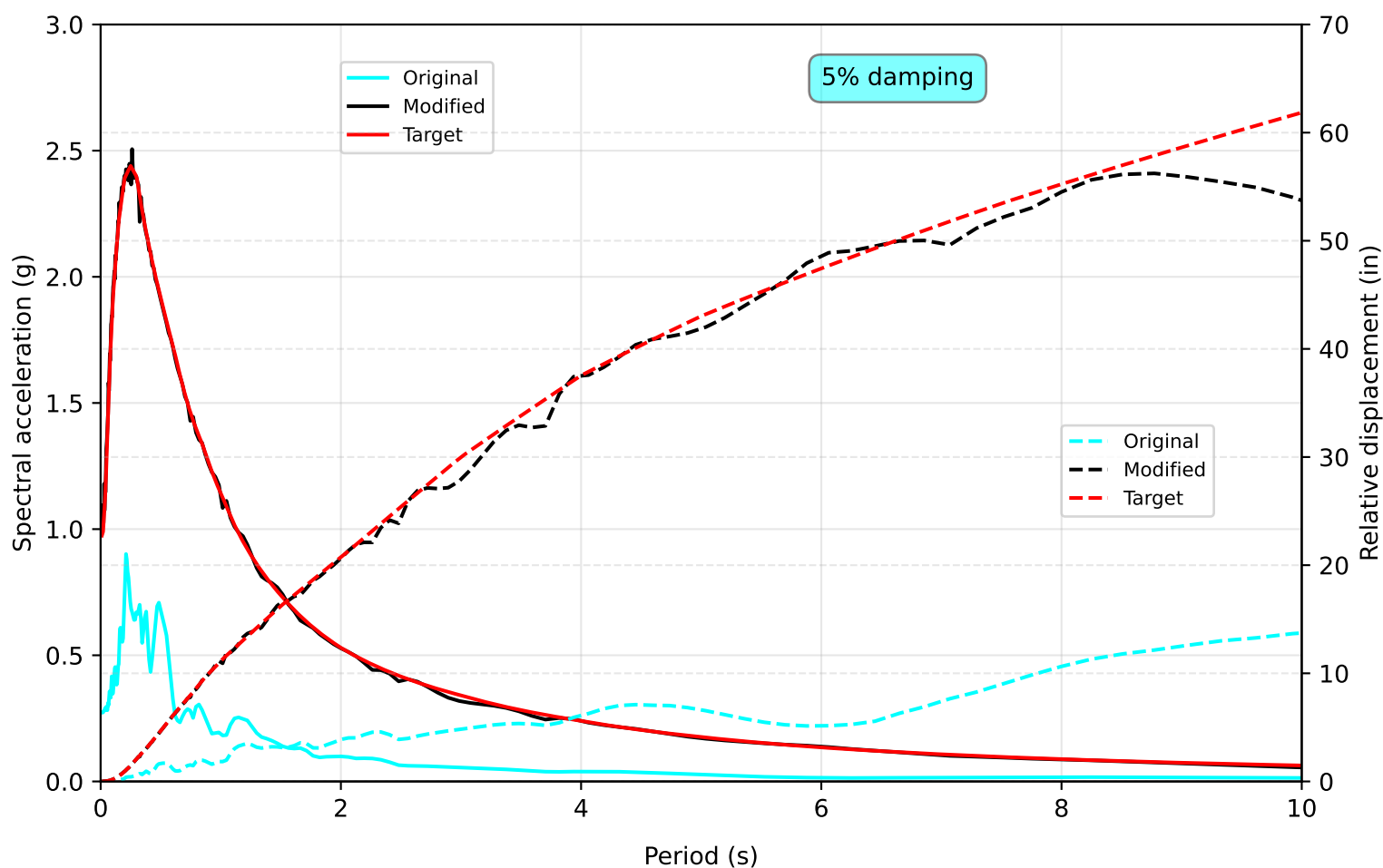
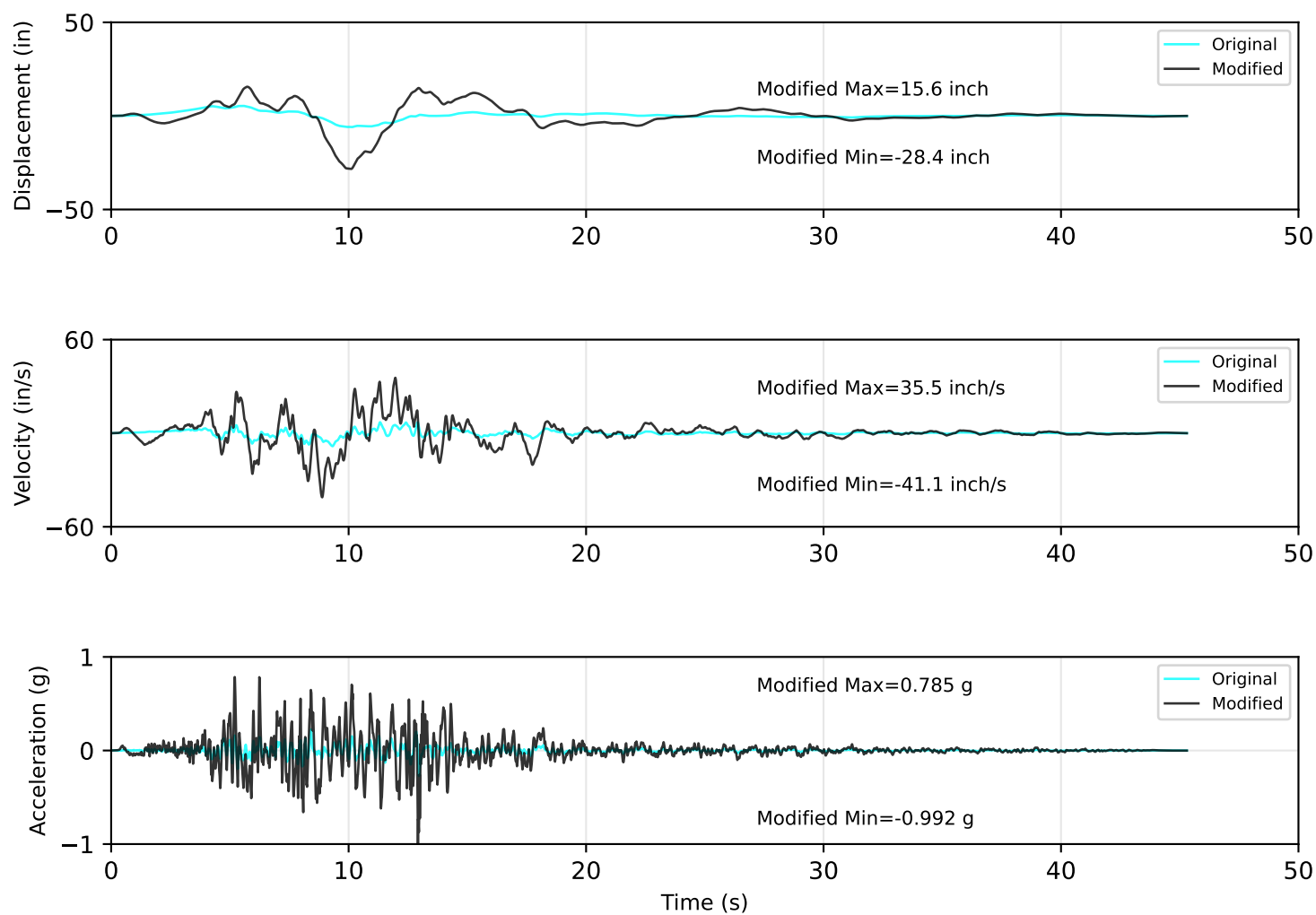


Figure B2. Reference Bedrock (Site Class C) ASCE 7-22 MCEr Spectrum-matched Ground Motion - Set-1-Fault Parallel

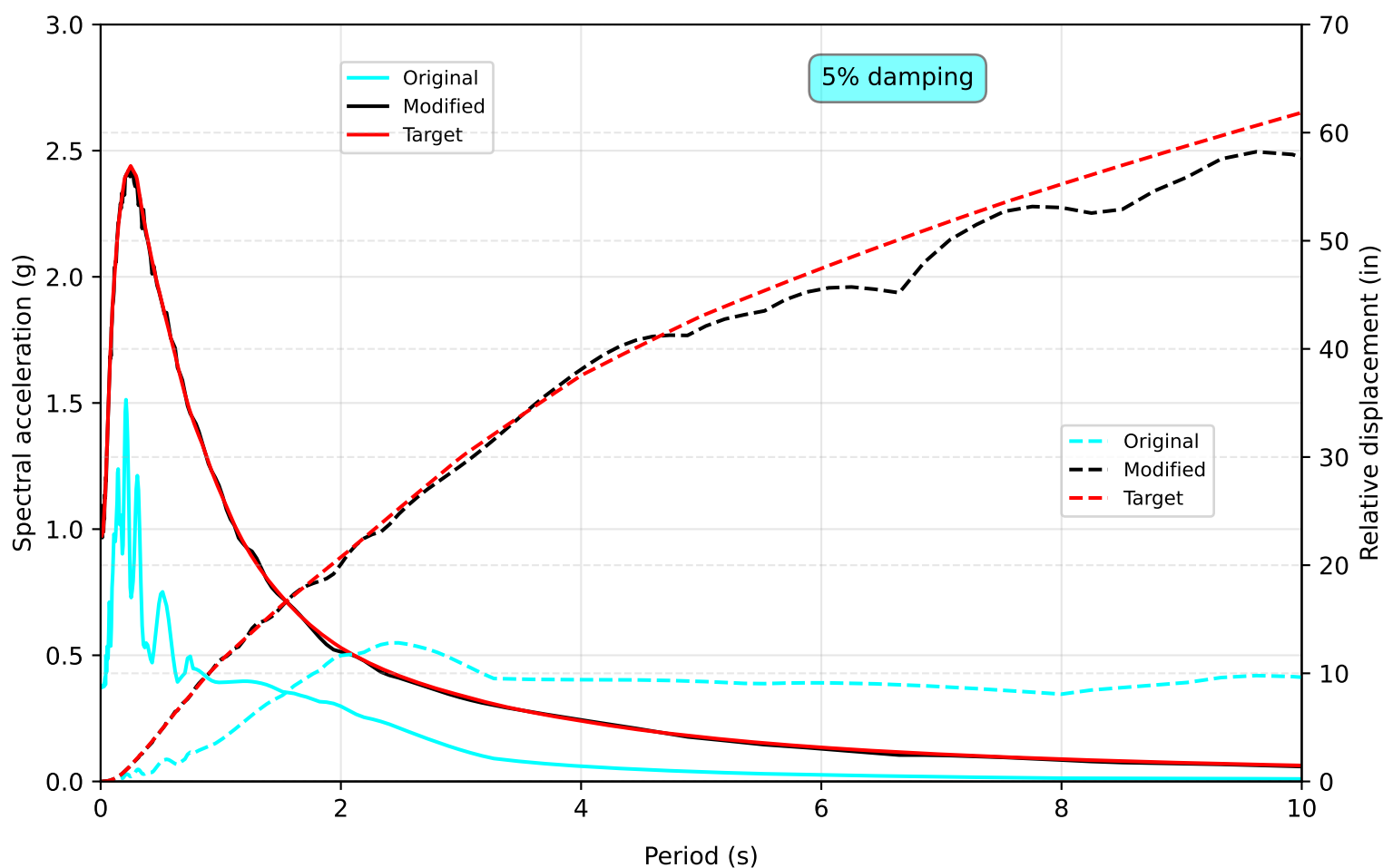
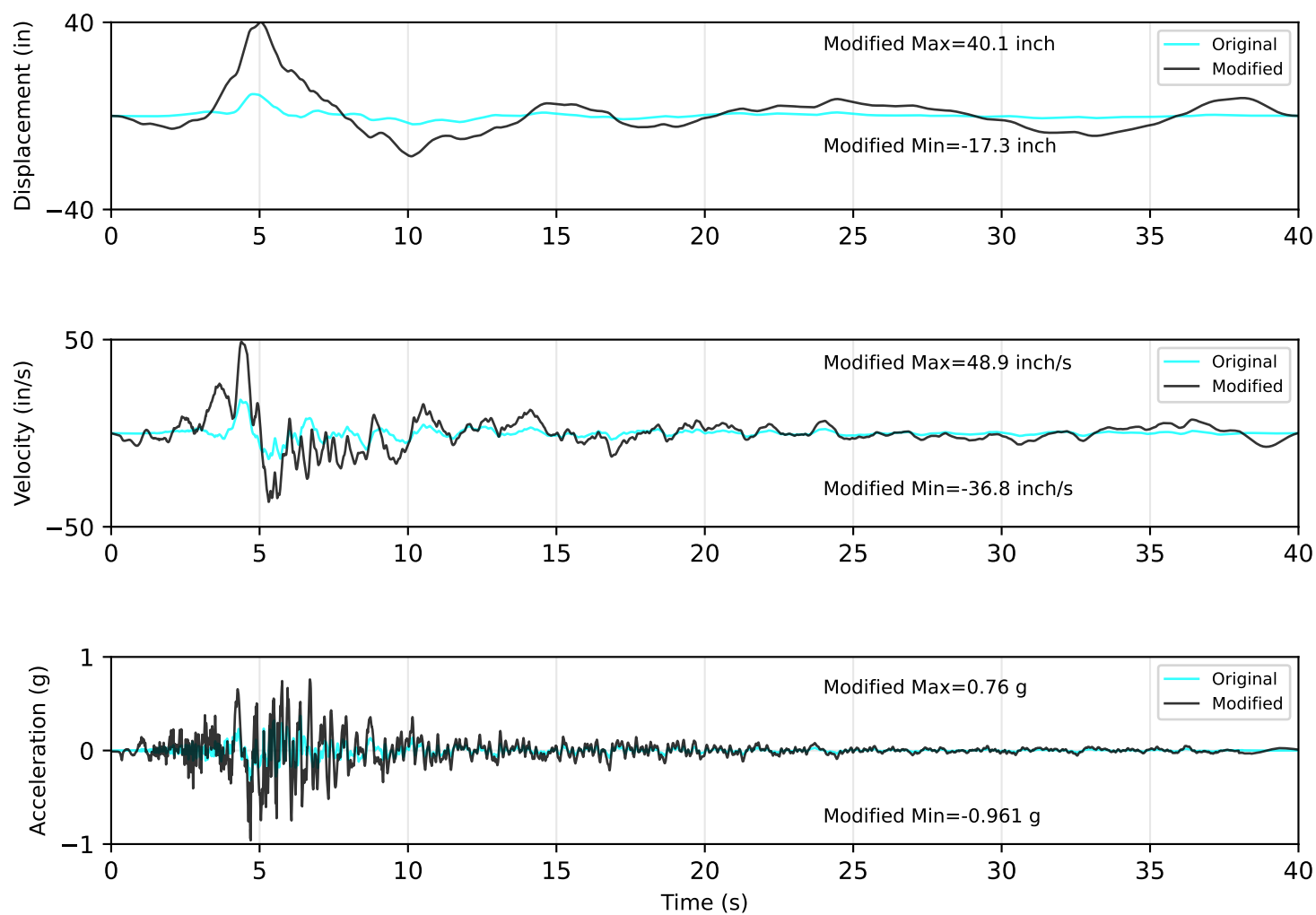


Figure B3. Reference Bedrock (Site Class C) ASCE 7-22 MCER Spectrum-matched Ground Motion - Set-2-Fault Normal

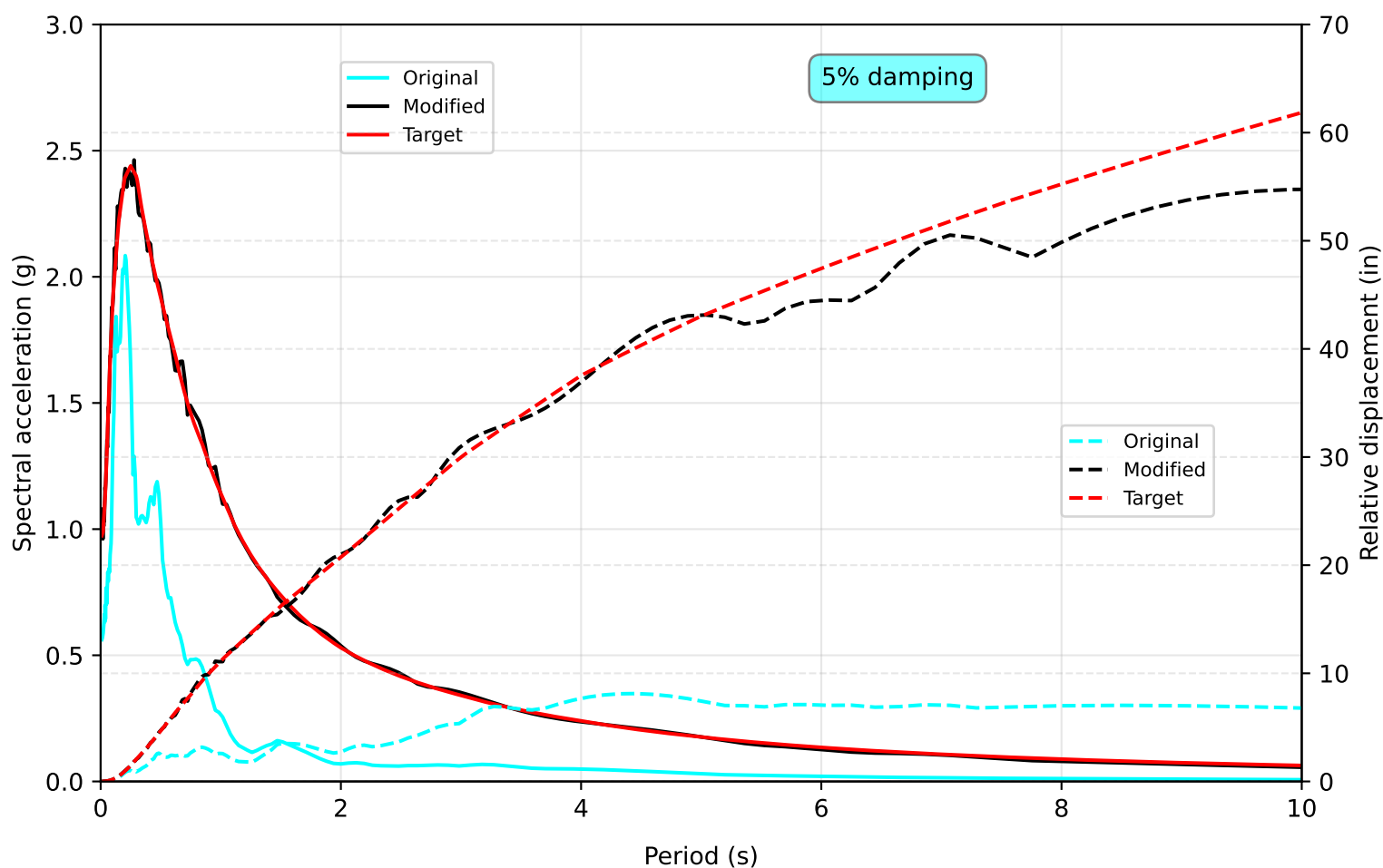
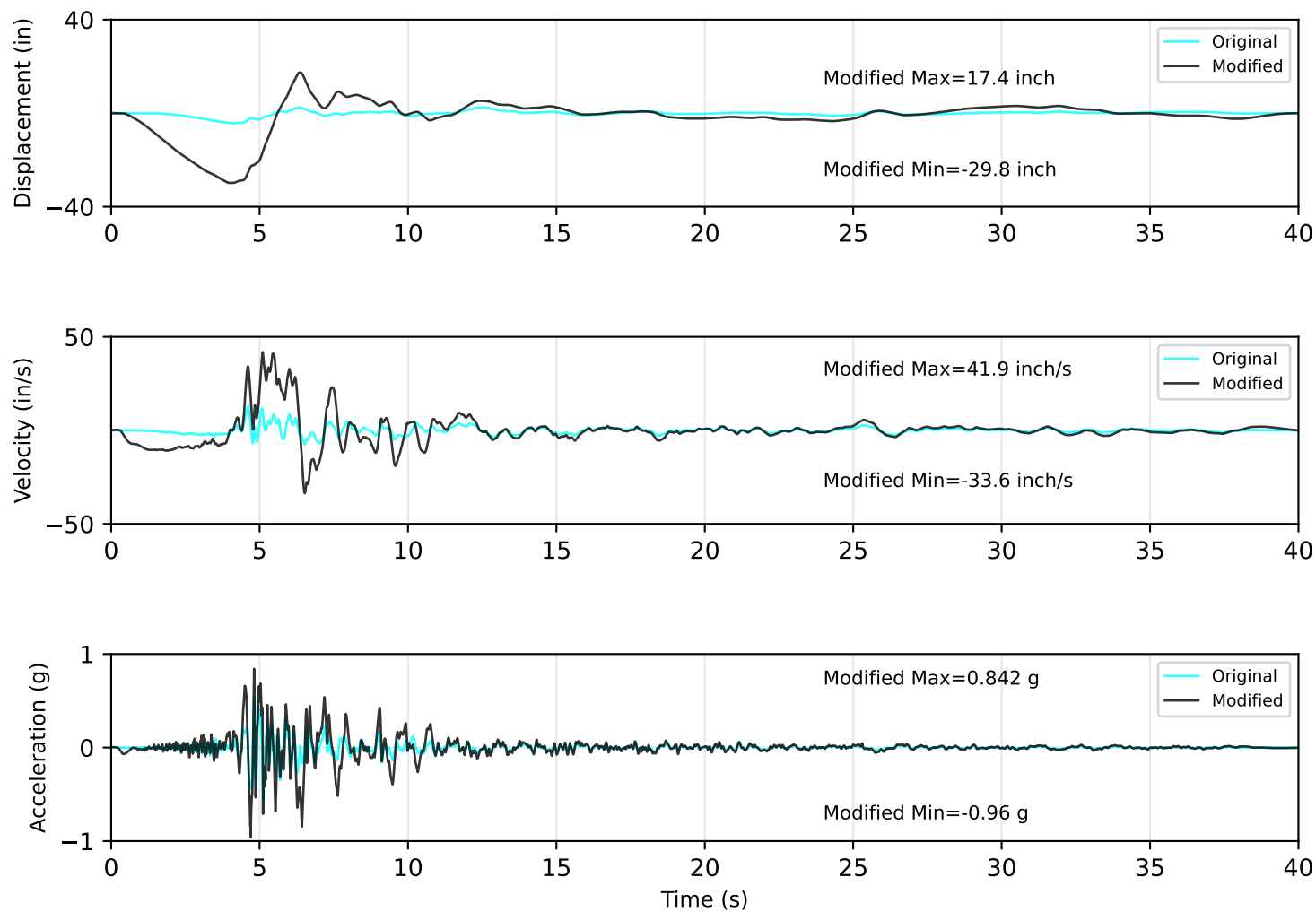


Figure B4. Reference Bedrock (Site Class C) ASCE 7-22 MCEr Spectrum-matched Ground Motion - Set-2-Fault Parallel

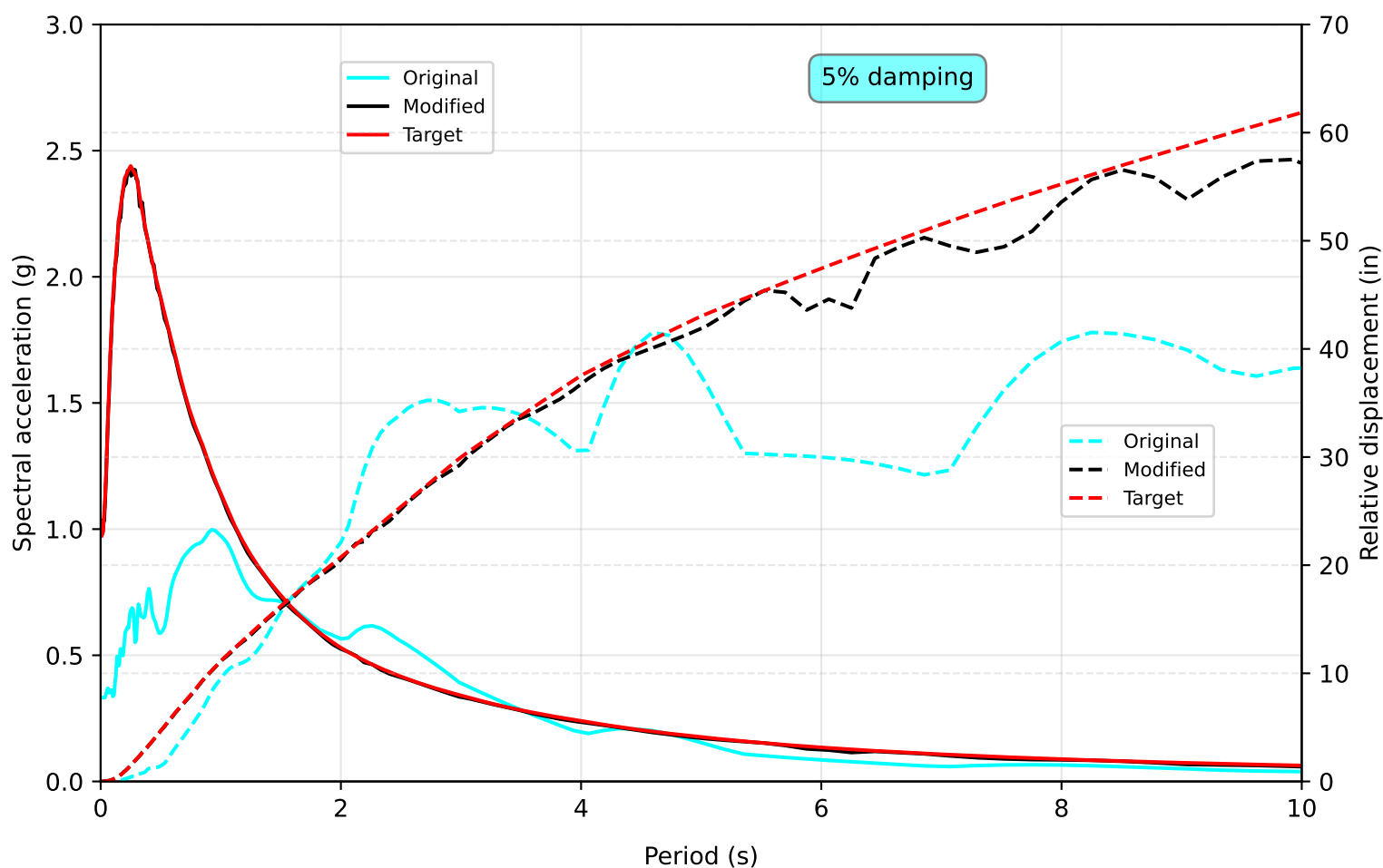
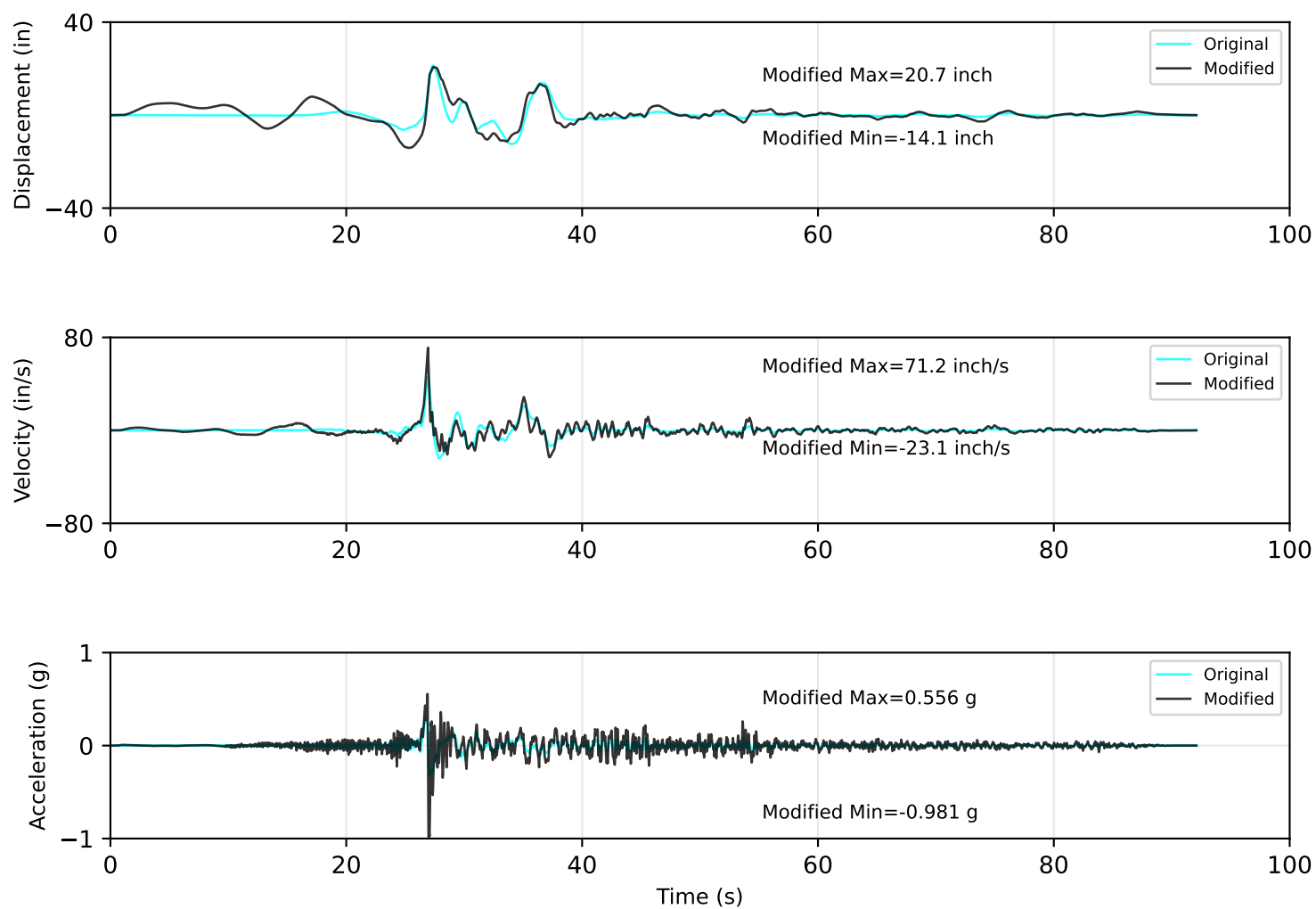


Figure B5. Reference Bedrock (Site Class C) ASCE 7-22 MCER Spectrum-matched Ground Motion - Set-3-Fault Normal

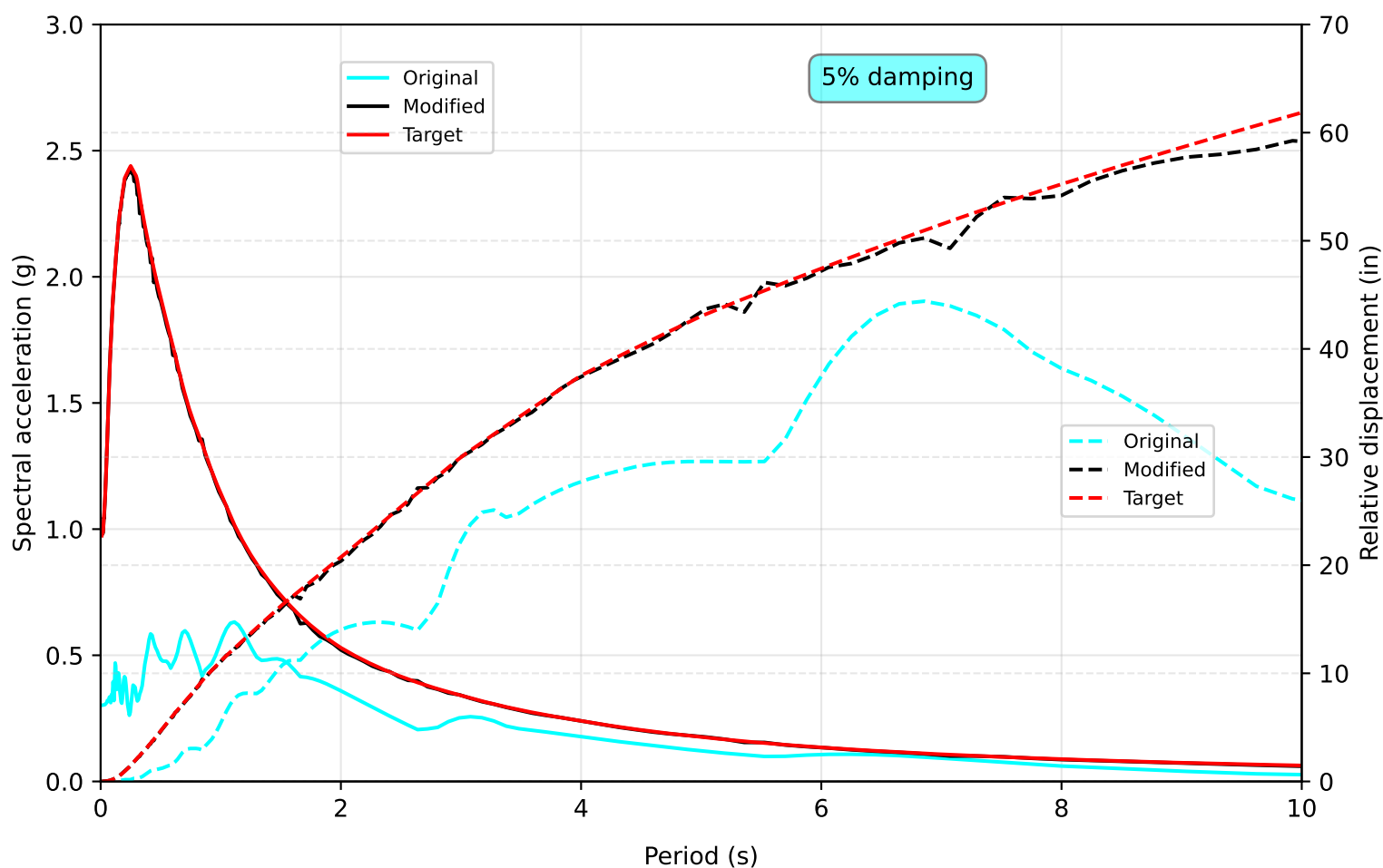
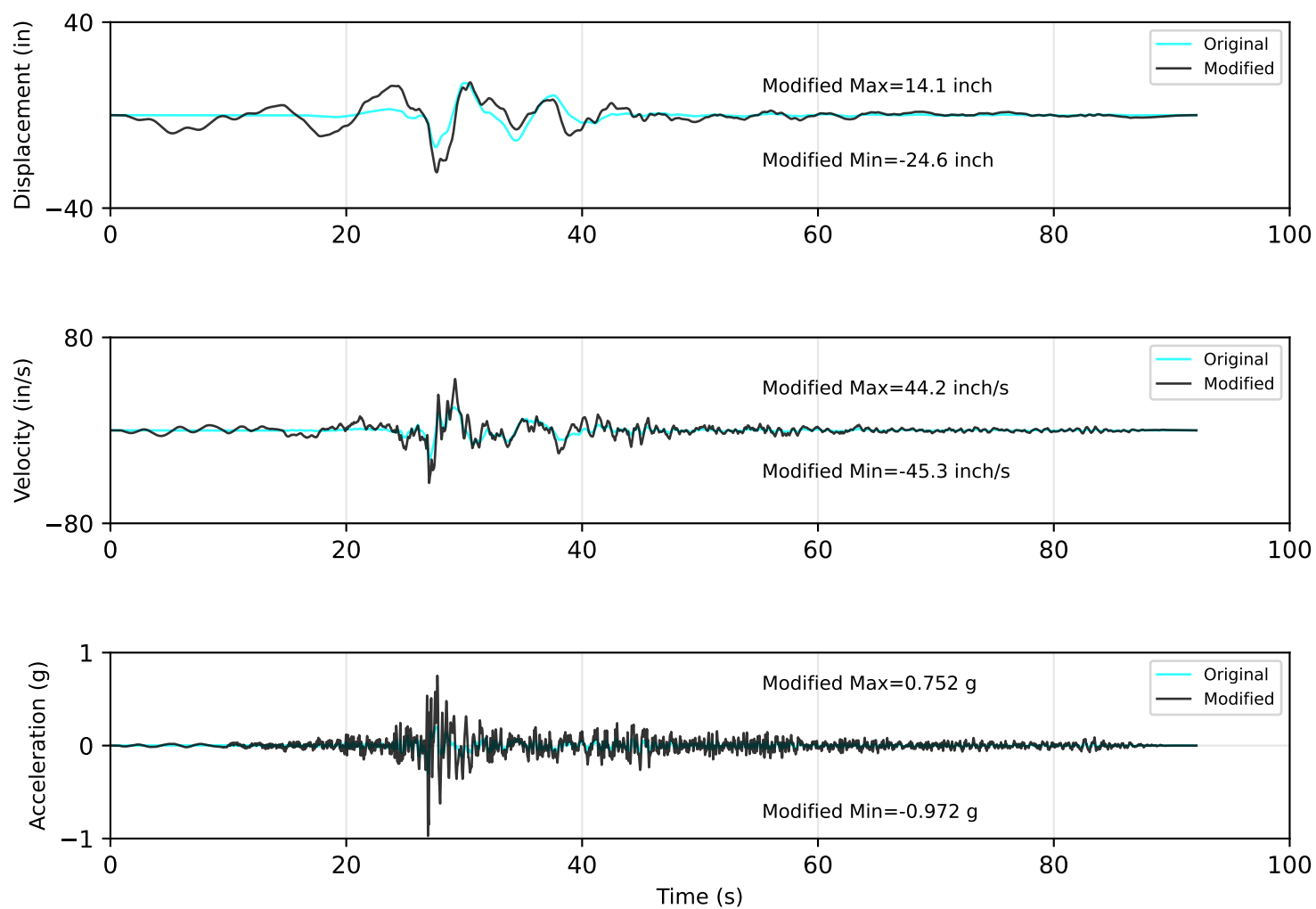


Figure B6. Reference Bedrock (Site Class C) ASCE 7-22 MCER Spectrum-matched Ground Motion - Set-3-Fault Parallel

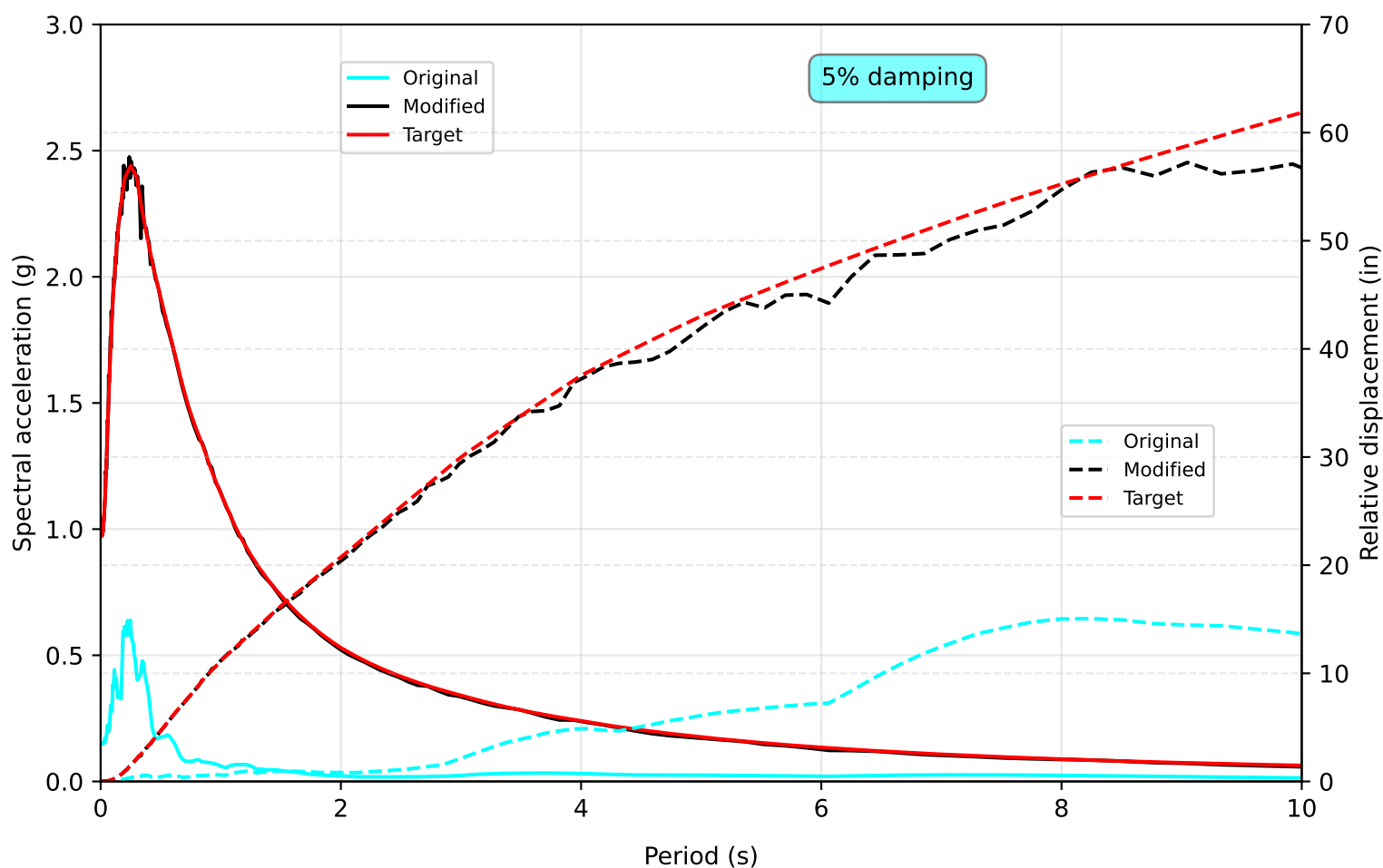
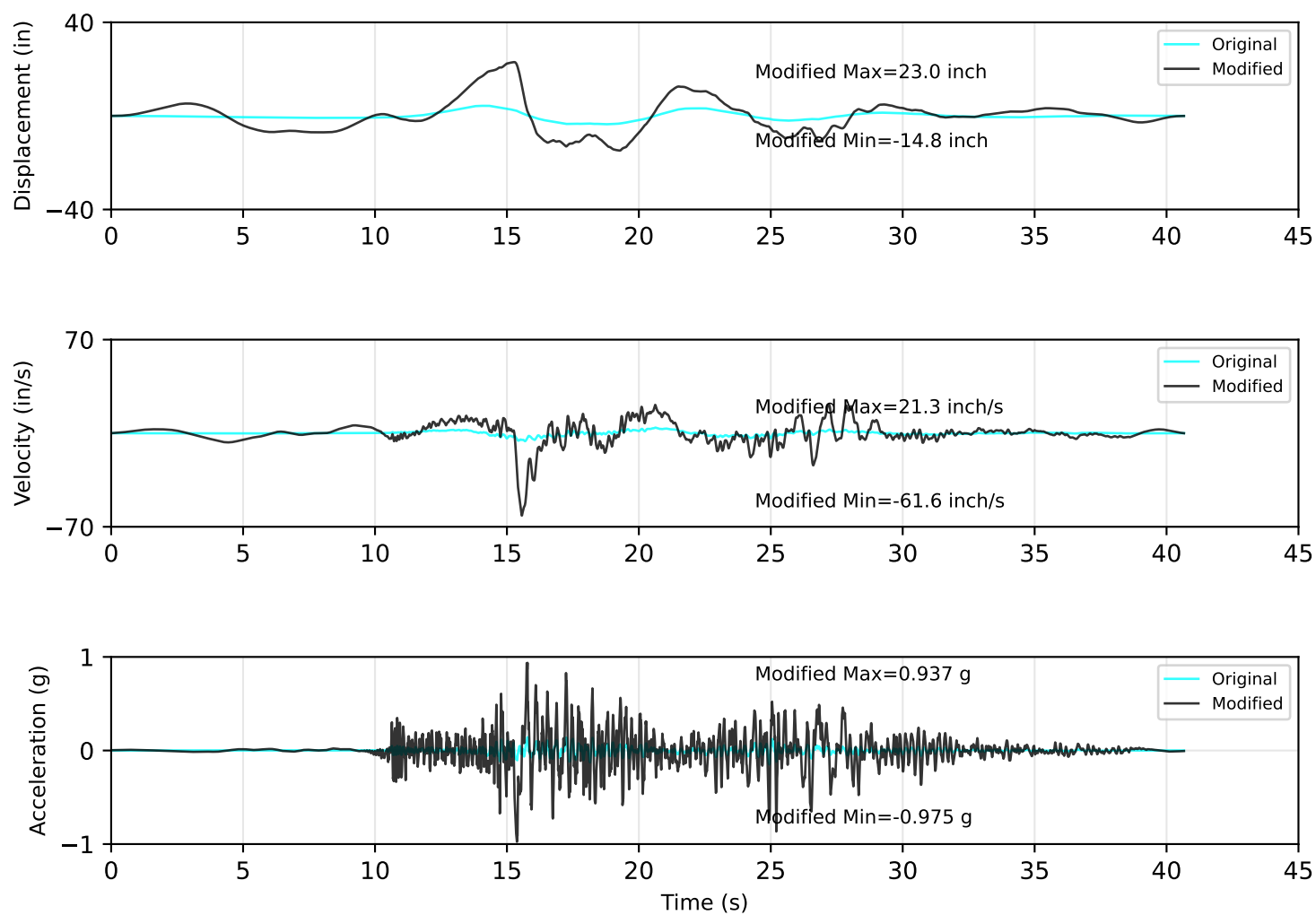


Figure B7. Reference Bedrock (Site Class C) ASCE 7-22 MCER Spectrum-matched Ground Motion - Set-4-Fault Normal

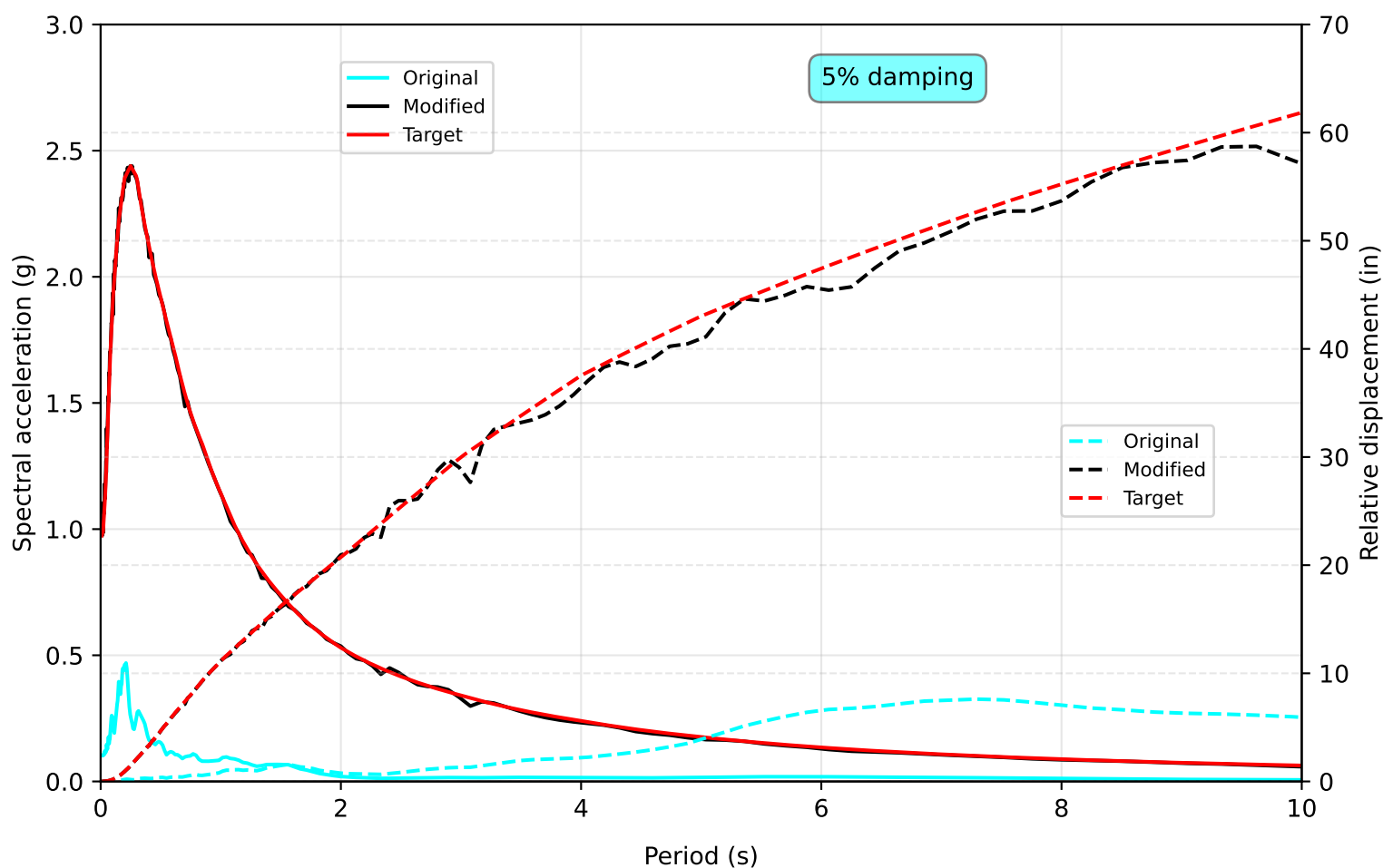
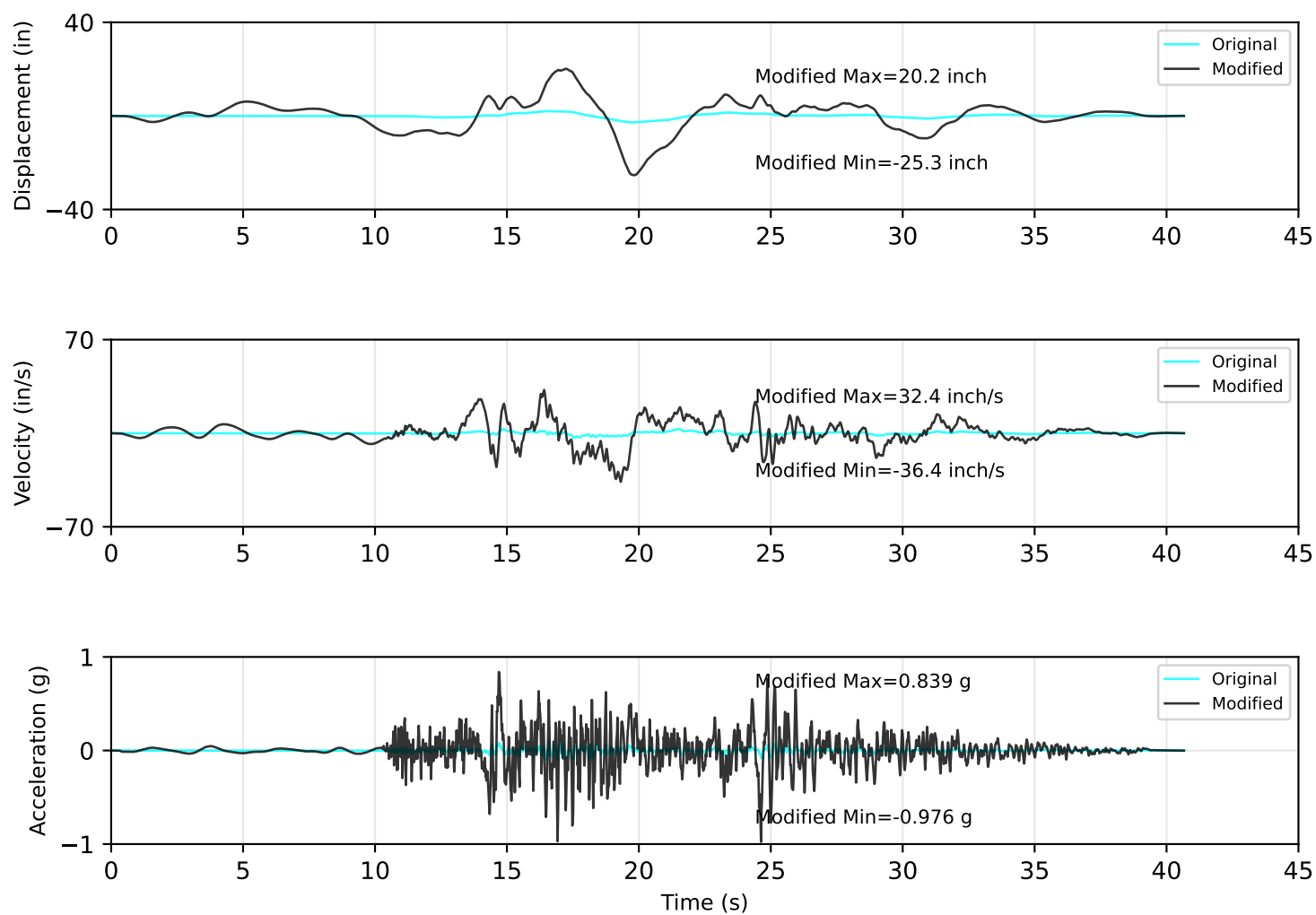


Figure B8. Reference Bedrock (Site Class C) ASCE 7-22 MCEr Spectrum-matched Ground Motion - Set-4-Fault Parallel

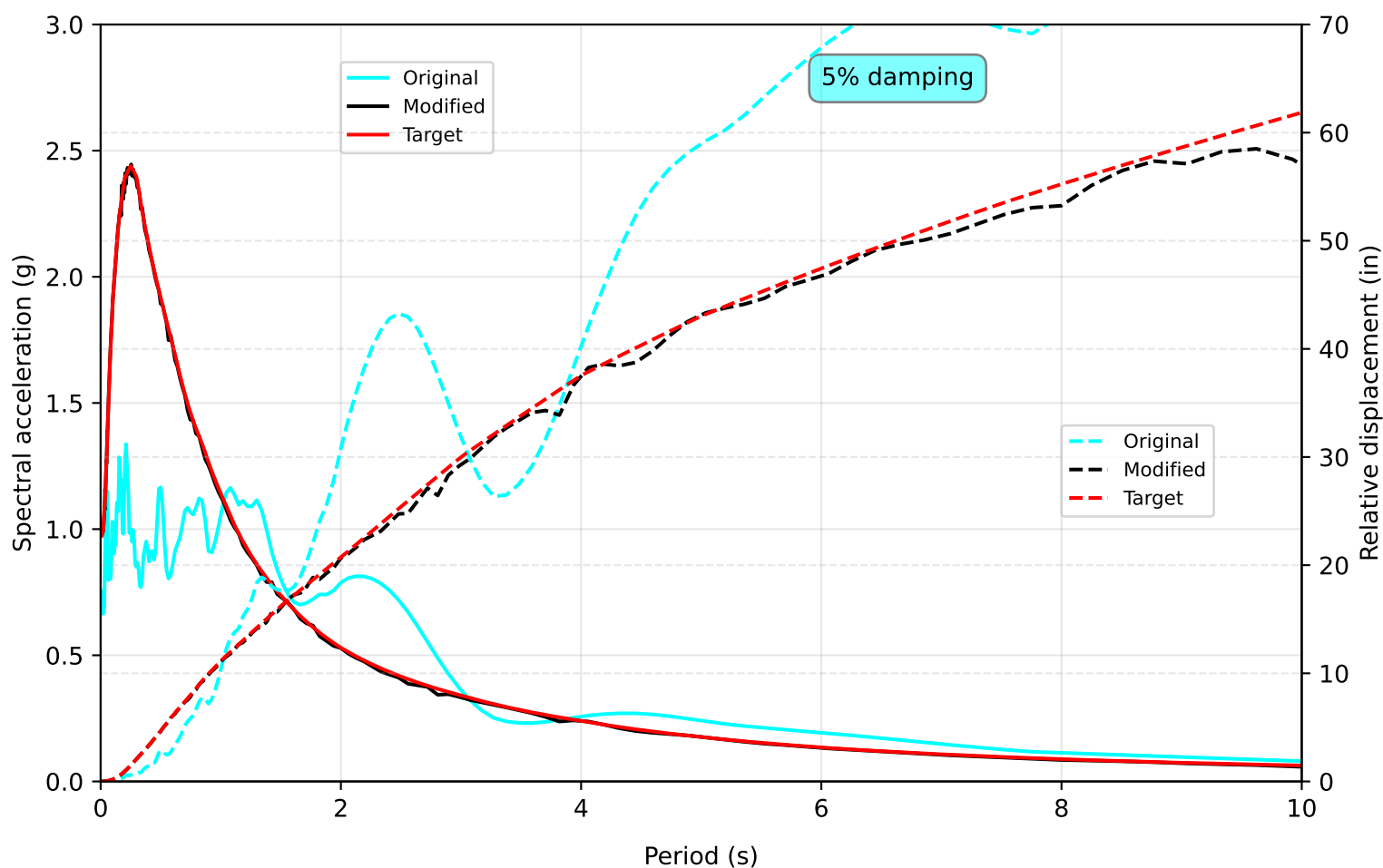
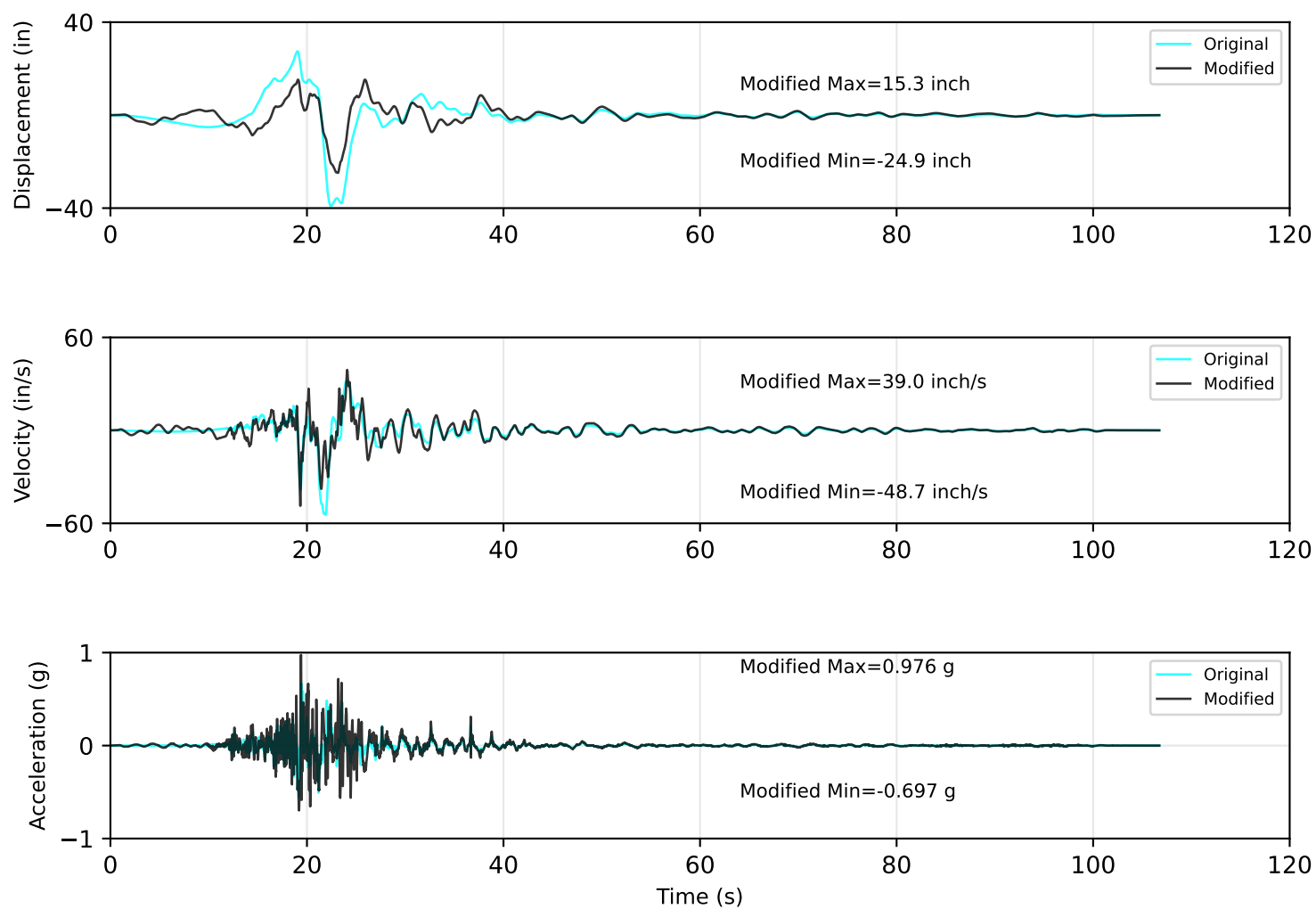


Figure B9. Reference Bedrock (Site Class C) ASCE 7-22 MCER Spectrum-matched Ground Motion - Set-5-Fault Normal

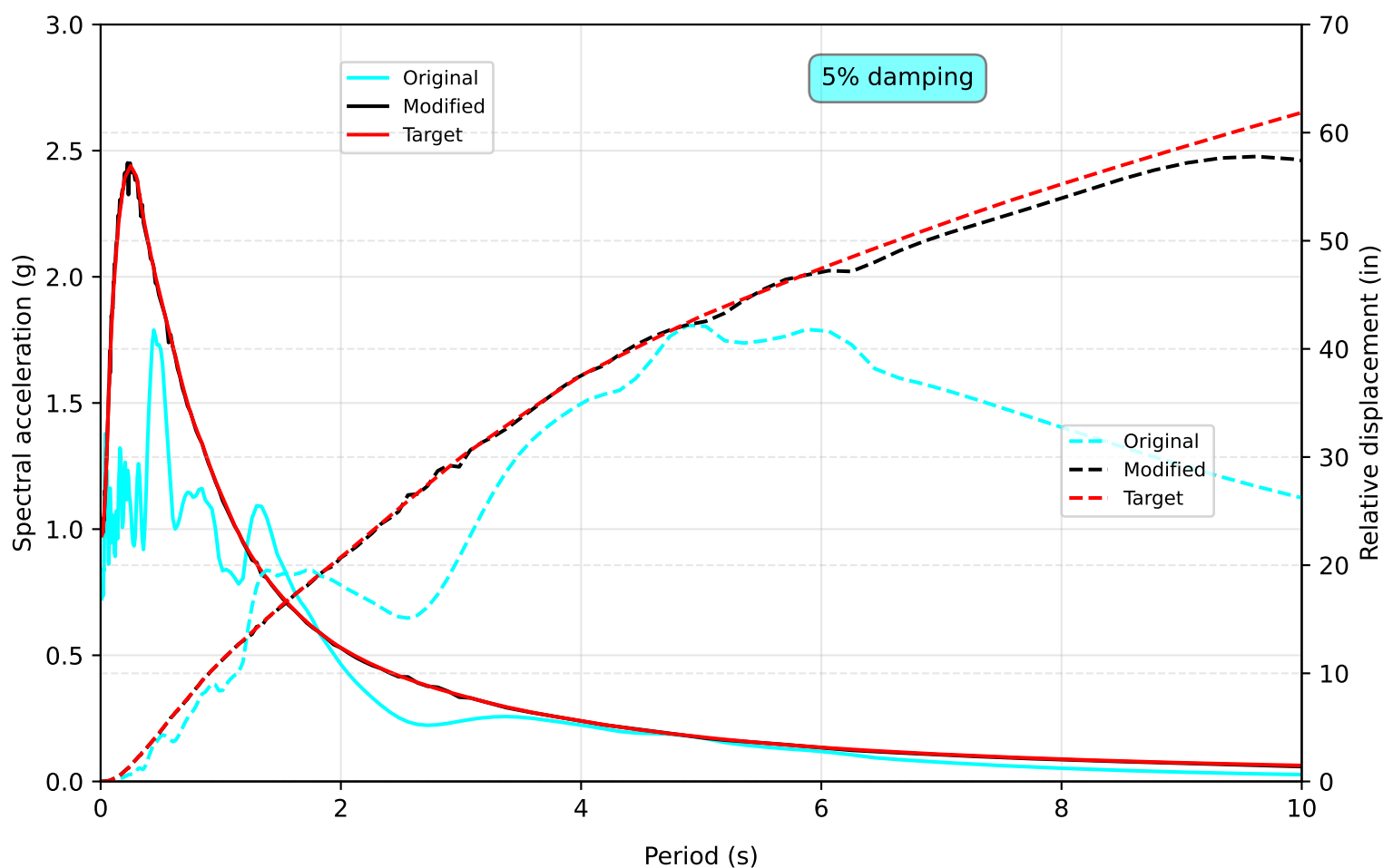
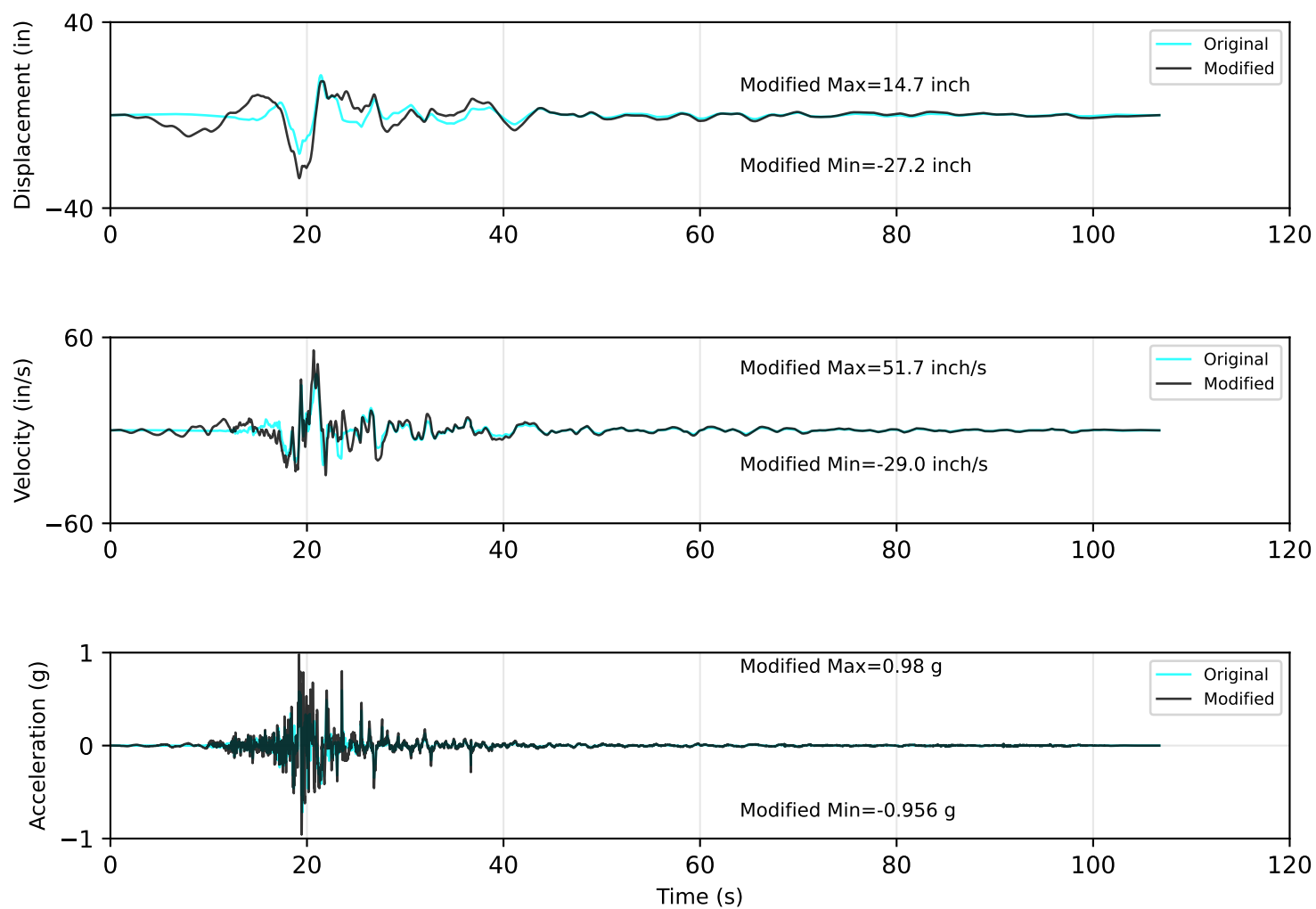


Figure B10. Reference Bedrock (Site Class C) ASCE 7-22 MCEr Spectrum-matched Ground Motion - Set-5-Fault Parallel

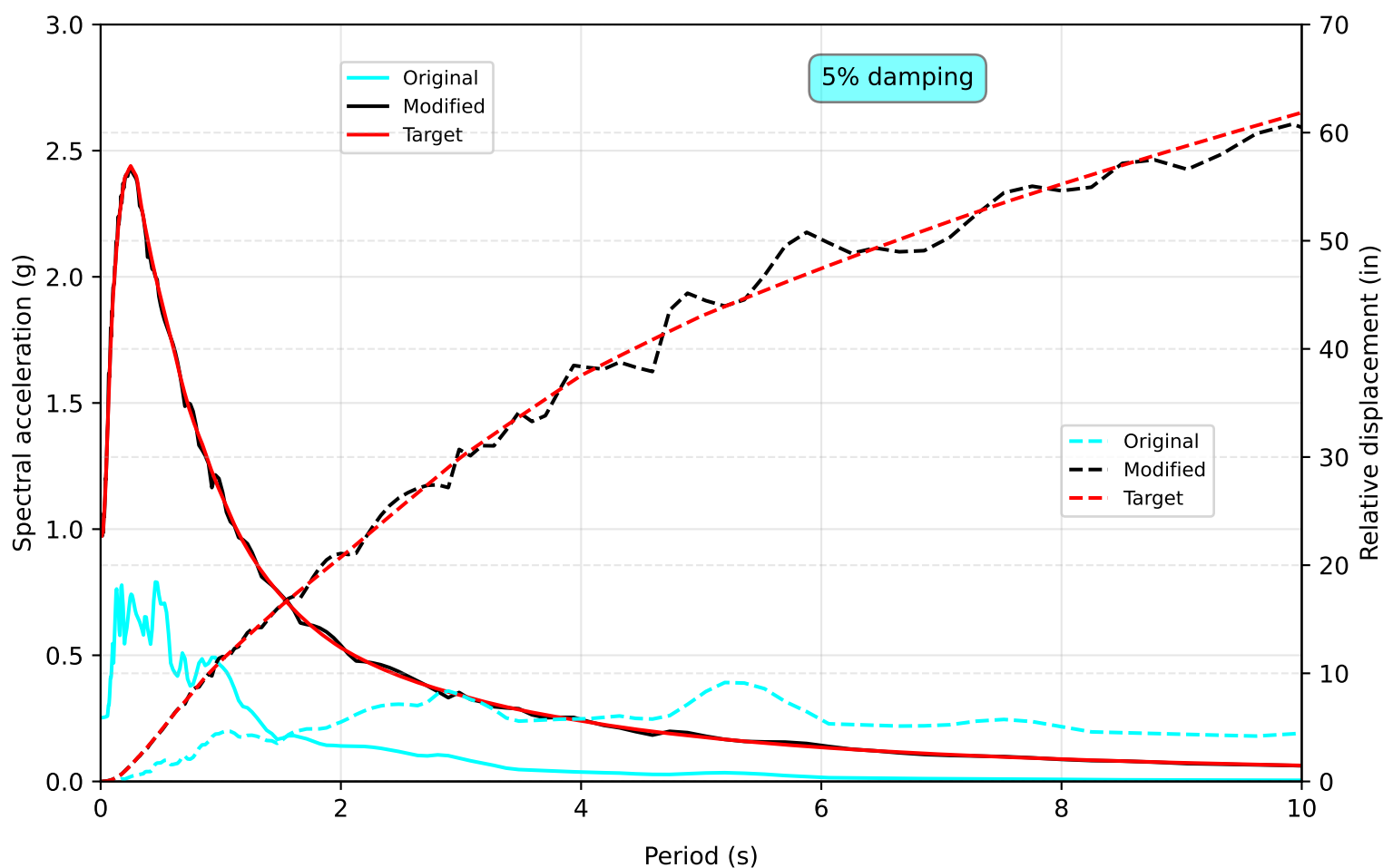
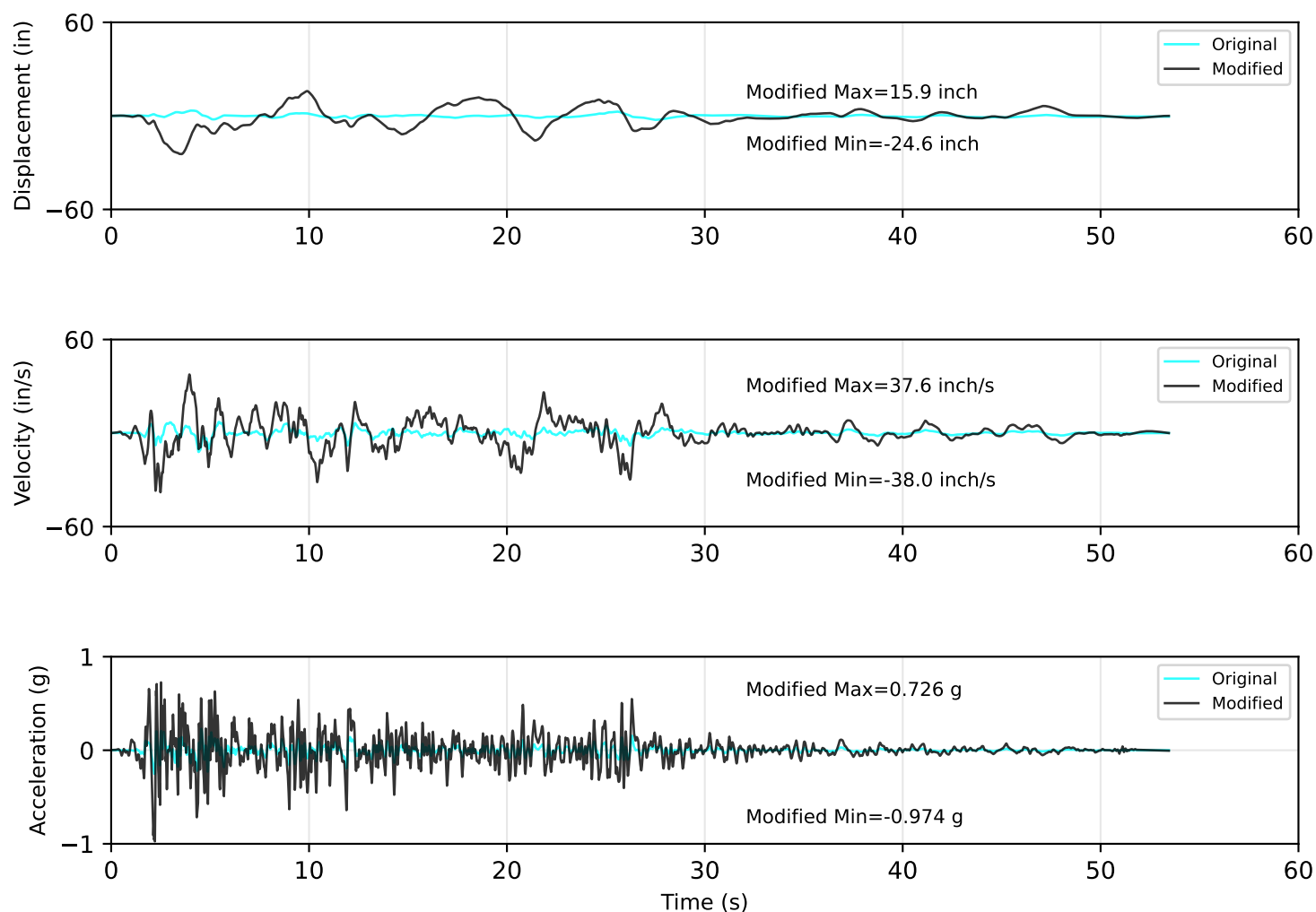


Figure B11. Reference Bedrock (Site Class C) ASCE 7-22 MCEr Spectrum-matched Ground Motion - Set-6-Fault Normal

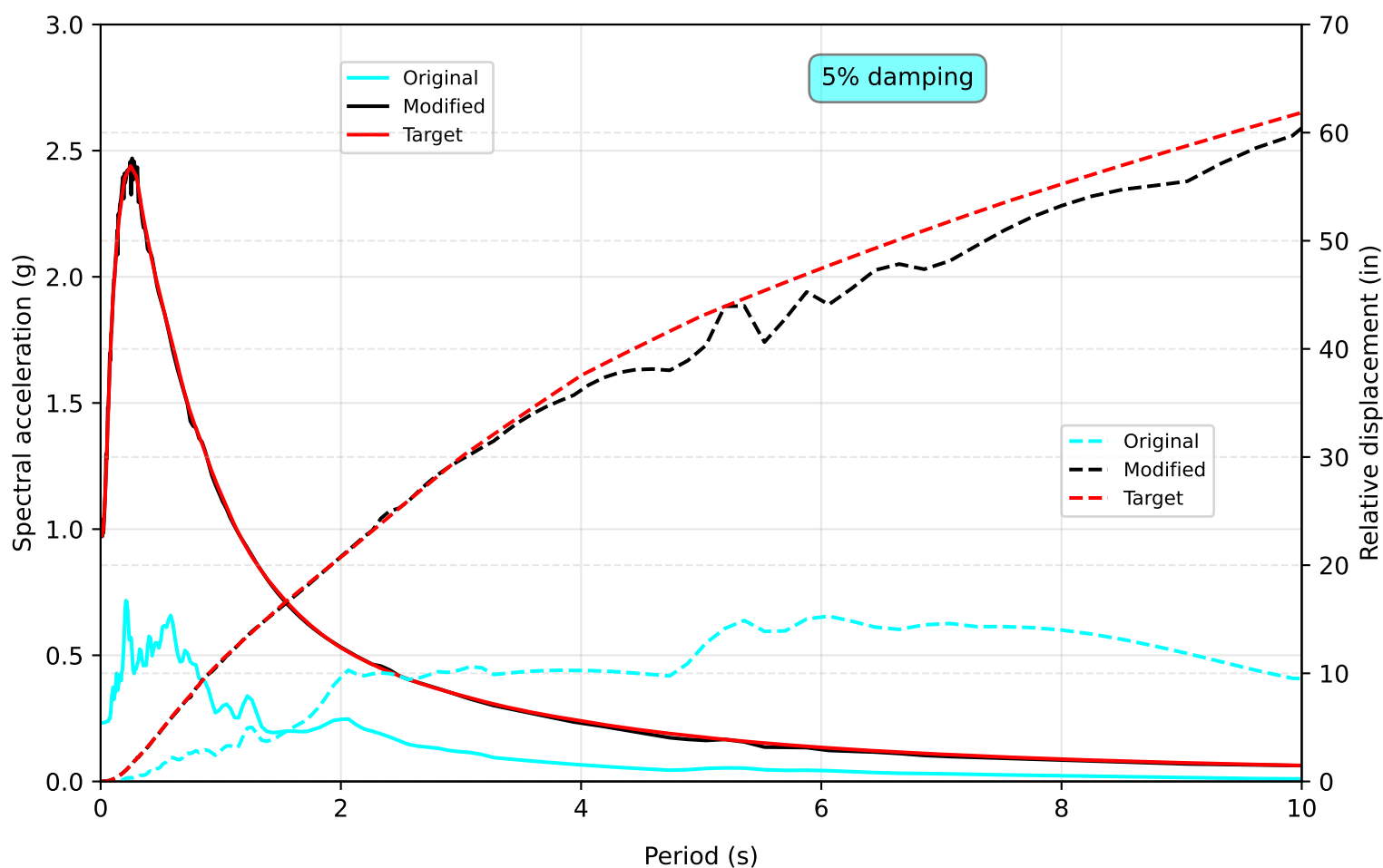
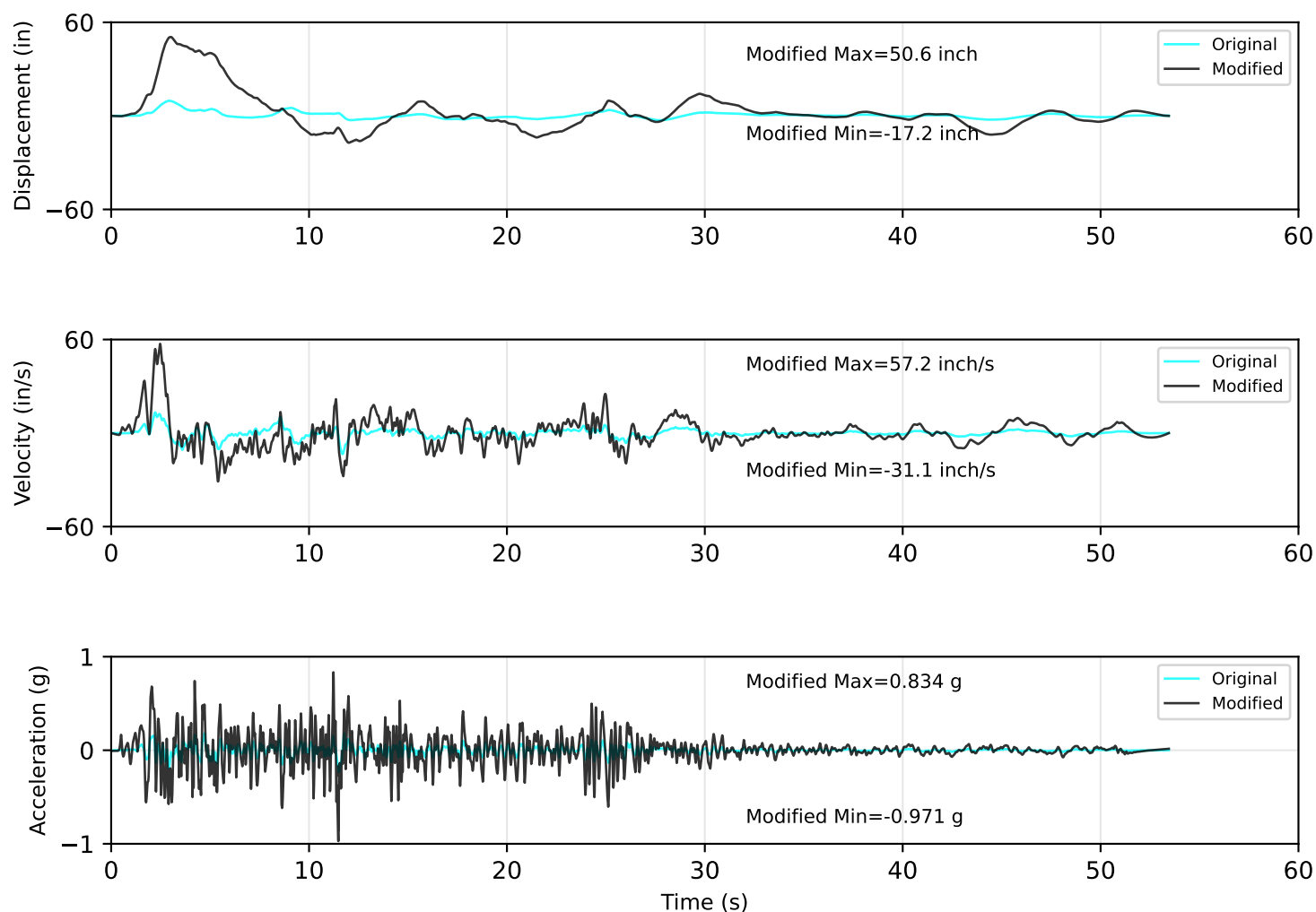


Figure B12. Reference Bedrock (Site Class C) ASCE 7-22 MCEr Spectrum-matched Ground Motion - Set-6-Fault Parallel

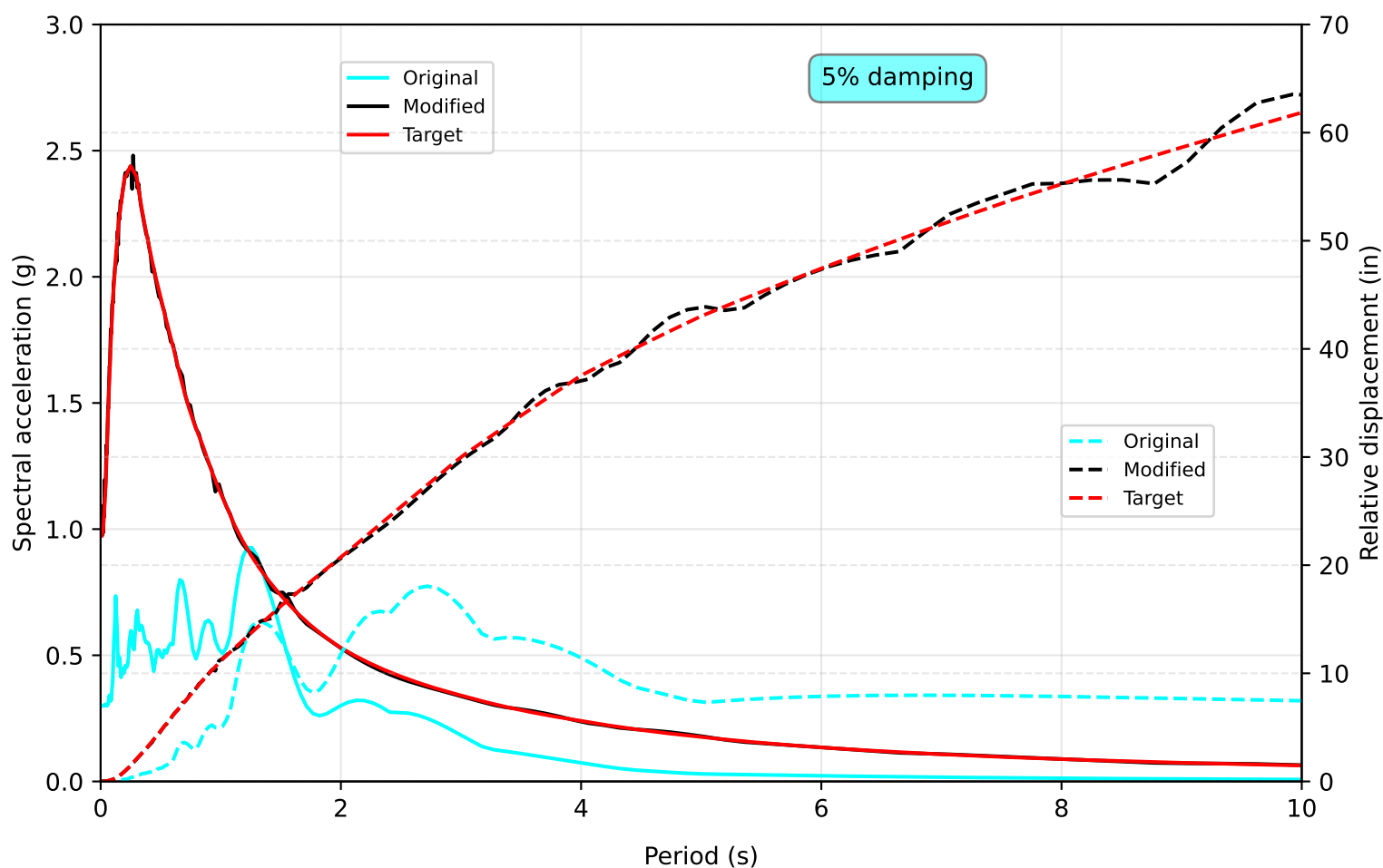
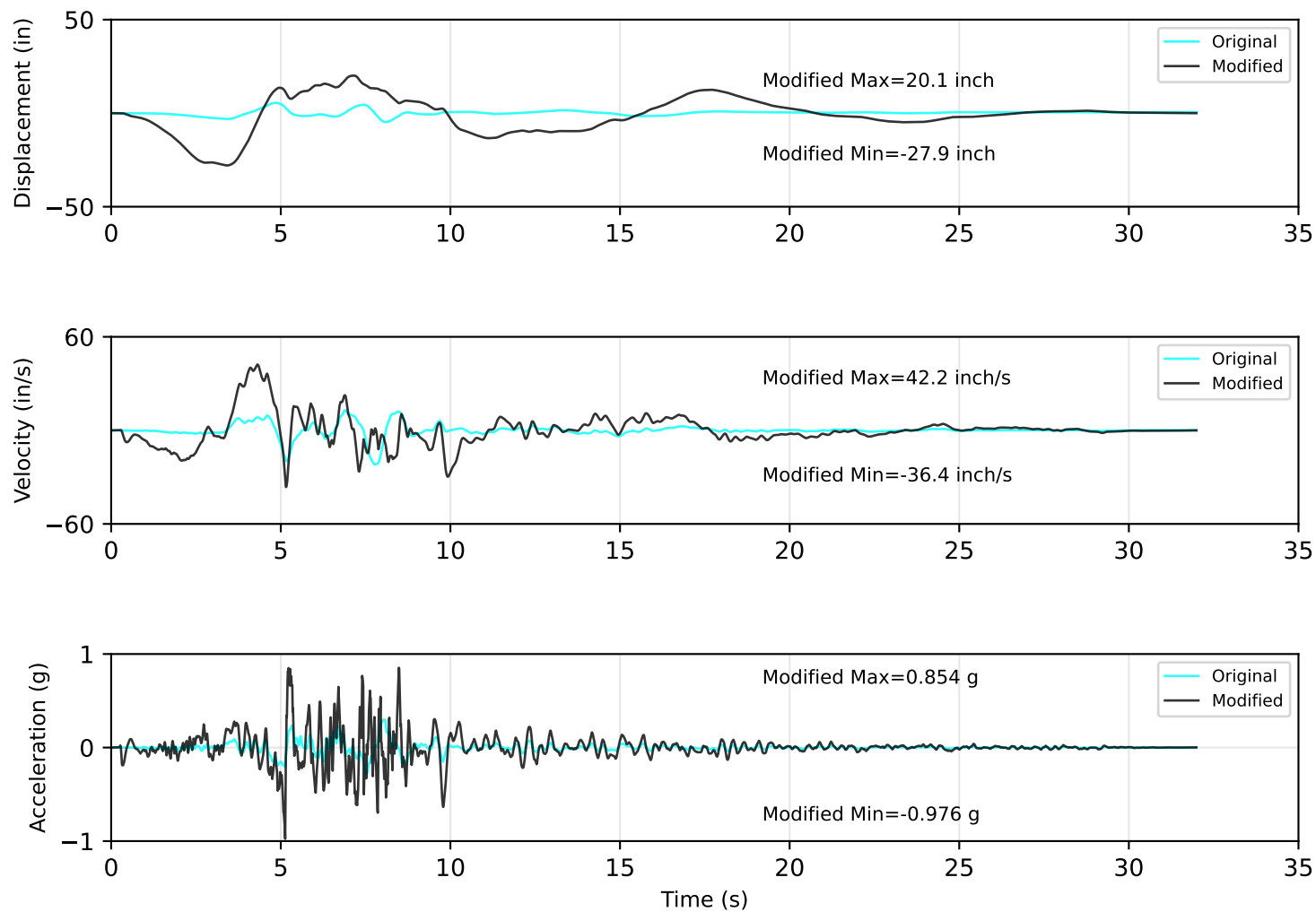


Figure B13. Reference Bedrock (Site Class C) ASCE 7-22 MCEr Spectrum-matched Ground Motion - Set-7-Fault Normal

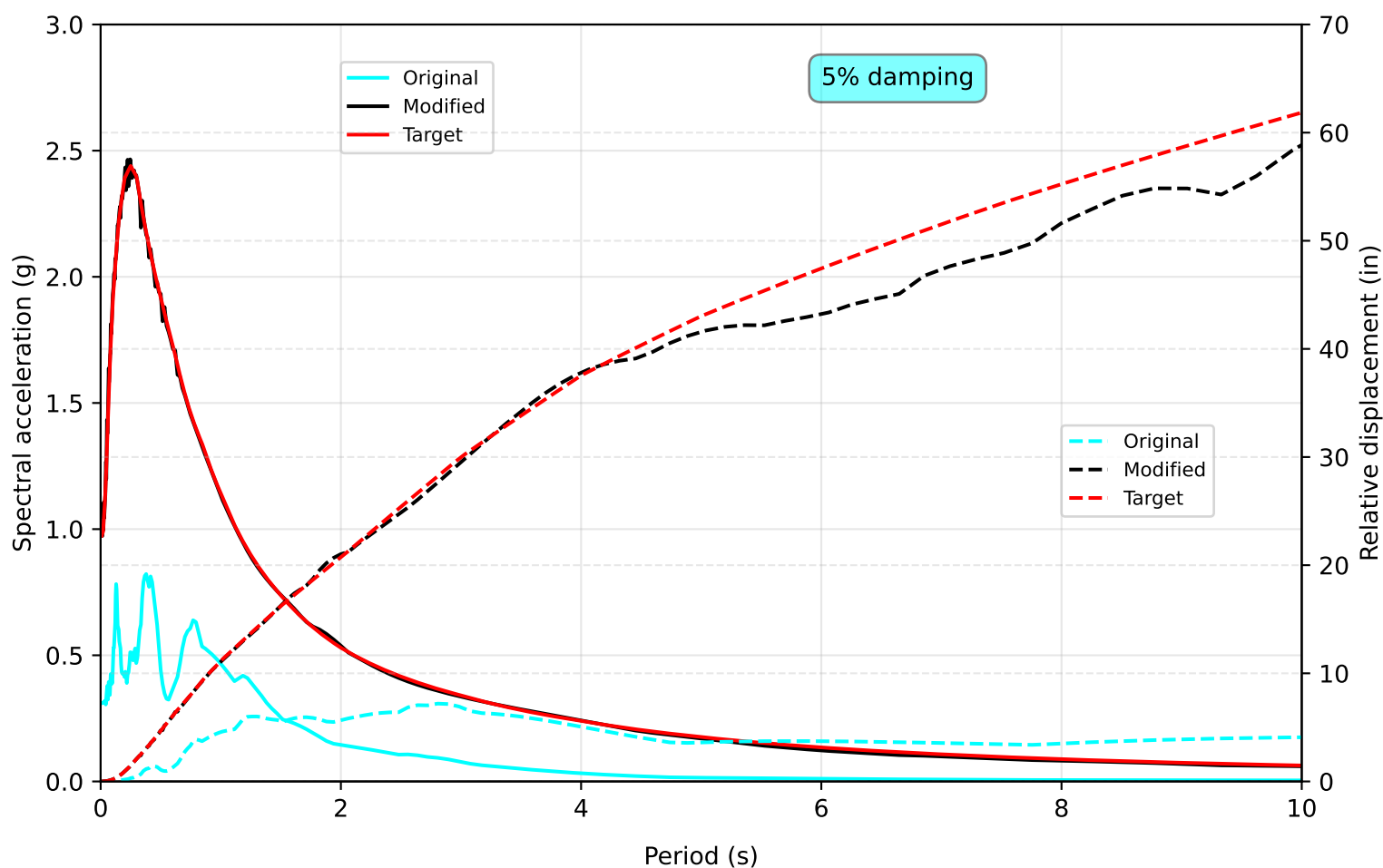
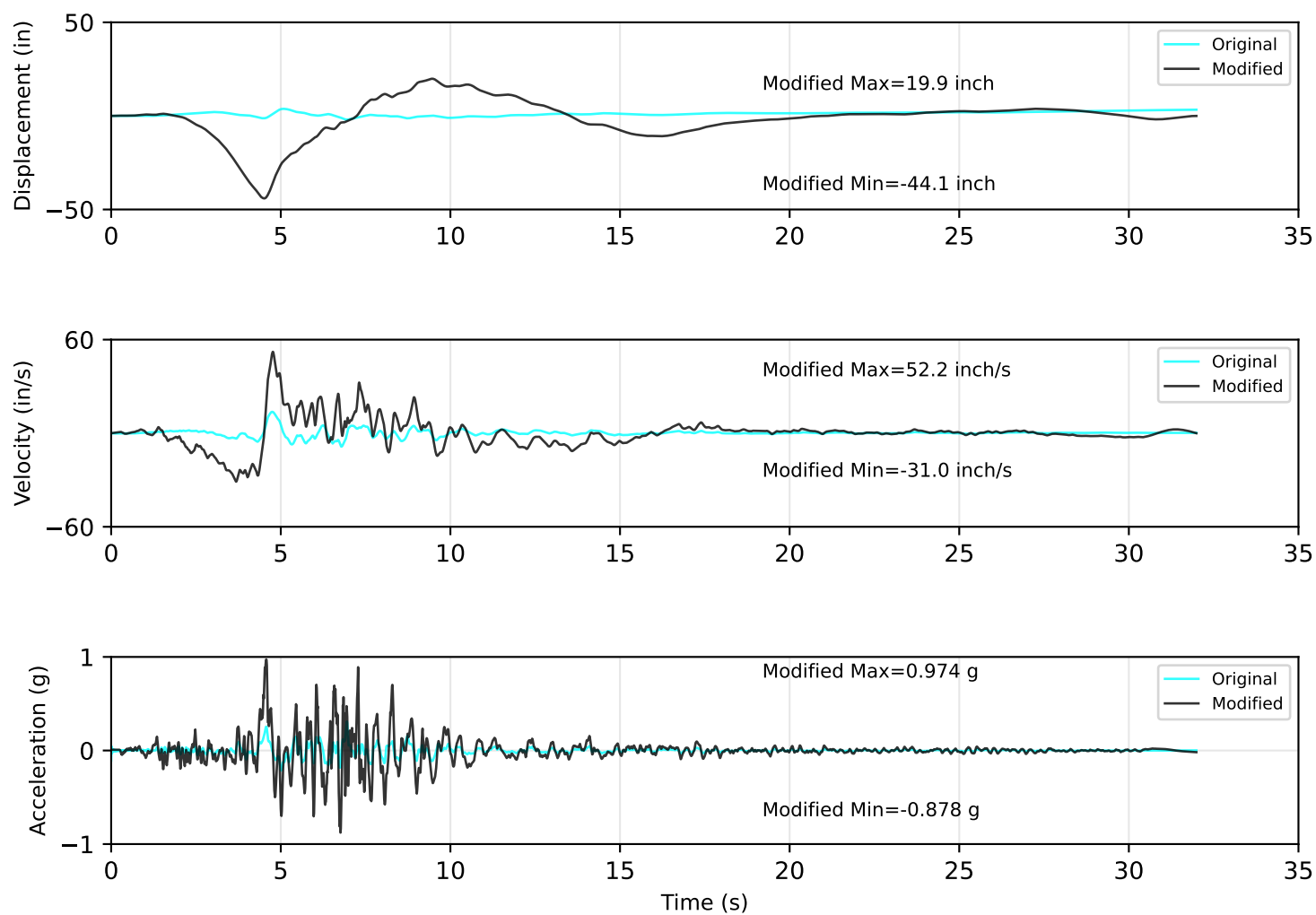


Figure B14. Reference Bedrock (Site Class C) ASCE 7-22 MCEr Spectrum-matched Ground Motion - Set-7-Fault Parallel

**APPENDIX C LOWER-, UPPER-ESTIMATE AND LIQUIFIED SOIL CONDITIONS
INPUT SOIL PARAMETERS USED FOR SITE RESPONSE ANALYSIS**

POLB - Zone I (Lower- and Upper-Bound Estimates of Soil Properties)

				Shear Wave Velocity (ft/s)			Reference Curves			Shear strength Prameters						Equivalent Shear Strength (psf)	
Layer No.	Depth (ft) - Layer Middle	Layer Thickness (ft)	Unit Weight (pcf)	Lower Bound	Baseline	Upper Bound	G/Gmax and D/Dmax	LB ko	UB ko	PI	Eff. Ver. Stress (psf)	LB Cohesion (psf)	UB Cohesion (psf)	LB Friction Angle (deg)	UB Friction Angle (deg)	Lower Bound	Upper Bound
1	1.25	2.5	120	528	600	672	"0-20 ft"	0.47	0.43	-	150	50	100	32	35	300	765
2	3.75	2.5	120	528	600	672	"0-20 ft"	0.47	0.43	-	450	50	100	32	35	487	975
3	6.25	2.5	120	528	600	672	"0-20 ft"	0.47	0.43	-	750	50	100	32	35	675	1185
4	8.75	2.5	120	528	600	672	"0-20 ft"	0.47	0.43	-	1050	50	100	32	35	862	1395
5	11.25	2.5	120	484	550	616	"0-20 ft"	0.47	0.43	-	1272	50	100	32	35	1001	1551
6	13.75	2.5	120	484	550	616	"0-20 ft"	0.47	0.43	-	1416	50	100	32	35	1091	1652
7	16.25	2.5	120	484	550	616	"0-20 ft"	0.47	0.43	-	1560	50	100	32	35	1181	1752
8	18.75	2.5	120	484	550	616	"0-20 ft"	0.47	0.43	-	1704	50	100	32	35	1271	1853
9	21.25	2.5	120	572	650	728	"20 to 50 ft"	0.47	0.43	-	1848	50	100	32	35	1361	1954
10	23.75	2.5	120	572	650	728	"20 to 50 ft"	0.47	0.43	-	1992	50	100	32	35	1451	2055
11	26.25	2.5	120	572	650	728	"20 to 50 ft"	0.47	0.43	-	2136	50	100	32	35	1541	2156
12	28.75	2.5	120	572	650	728	"20 to 50 ft"	0.47	0.43	-	2280	50	100	32	35	1631	2257
13	31.25	2.5	120	704	800	896	"20 to 50 ft"	0.47	0.43	-	2424	50	100	32	35	1721	2357
14	33.75	2.5	120	704	800	896	"20 to 50 ft"	0.47	0.43	-	2568	50	100	32	35	1811	2458
15	36.25	2.5	120	704	800	896	"20 to 50 ft"	0.47	0.43	-	2712	50	100	32	35	1901	2559
16	38.75	2.5	120	704	800	896	"20 to 50 ft"	0.47	0.43	-	2856	50	100	32	35	1991	2660
17	41.25	2.5	120	704	800	896	"20 to 50 ft"	0.43	0.38	-	3000	100	100	35	38	2376	3069
18	43.75	2.5	120	704	800	896	"20 to 50 ft"	0.43	0.38	-	3144	100	100	35	38	2477	3181
19	46.25	2.5	120	704	800	896	"20 to 50 ft"	0.43	0.38	-	3288	100	100	35	38	2577	3294
20	48.75	2.5	120	704	800	896	"20 to 50 ft"	0.43	0.38	-	3432	100	100	35	38	2678	3406
21	51.25	2.5	120	704	800	896	"50 to 120 ft"	0.43	0.38	-	3576	100	100	35	38	2779	3519
22	53.75	2.5	120	704	800	896	"50 to 120 ft"	0.43	0.38	-	3720	100	100	35	38	2880	3631
23	56.25	2.5	120	704	800	896	"50 to 120 ft"	0.43	0.38	-	3864	100	100	35	38	2981	3744
24	60	5	120	704	800	896	"50 to 120 ft"	0.43	0.38	-	4080	100	100	35	38	3132	3913
25	65	5	120	704	800	896	"50 to 120 ft"	0.38	0.36	-	4368	100	100	38	40	3708	4436
26	70	5	120	730	830	930	"50 to 120 ft"	0.38	0.36	-	4656	100	100	38	40	3933	4678
27	75	5	120	757	860	963	"50 to 120 ft"	0.38	0.36	-	4944	100	100	38	40	4158	4920
28	80	5	120	783	890	997	"50 to 120 ft"	0.38	0.36	-	5232	100	100	38	40	4383	5161
29	85	5	120	810	920	1030	"50 to 120 ft"	0.38	0.36	-	5520	100	100	38	40	4608	5403
30	90	5	120	836	950	1064	"50 to 120 ft"	0.38	0.36	-	5808	100	100	38	40	4833	5645
31	95	5	120	862	980	1098	"50 to 120 ft"	0.38	0.36	-	6096	100	100	38	40	5058	5886
32	100	5	120	889	1010	1131	"50 to 120 ft"	0.38	0.36	-	6384	100	100	38	40	5283	6128
33	105	5	120	915	1040	1165	"50 to 120 ft"	0.38	0.36	-	6672	100	100	38	40	5508	6370
34	110	5	120	942	1070	1198	"50 to 120 ft"	0.38	0.36	-	6960	100	100	38	40	5733	6611
35	115	5	120	968	1100	1232	"50 to 120 ft"	0.38	0.36	-	7248	100	100	38	40	5958	6853
36	120	5	120	994	1130	1266	"50 to 120 ft"	0.38	0.36	-	7536	100	100	38	40	6183	7095
37	125	5	120	1021	1160	1299	"120 to 250 ft"	0.38	0.36	-	7824	100	100	38	40	6408	7336
38	130	5	120	1047	1190	1333	"120 to 250 ft"	0.38	0.36	-	8112	100	100	38	40	6633	7578
39	135	5	120	1074	1220	1366	"120 to 250 ft"	0.38	0.36	-	8400	100	100	38	40	6858	7820
40	140	5	120	1100	1250	1400	"120 to 250 ft"	0.38	0.36	-	8688	100	100	38	40	7083	8061
41	145	5	120	1126	1280	1434	"120 to 250 ft"	0.38	0.36	-	8976	100	100	38	40	7308	8303
42	150	5	120	1153	1310	1467	"120 to 250 ft"	0.38	0.36	-	9264	100	100	38	40	7533	8545
43	155	5	120	1157	1315	1473	"120 to 250 ft"	0.38	0.36	-	9552	100	100	38	40	7758	8786
44	160	5	120	1162	1320	1478	"120 to 250 ft"	0.38	0.36	-	9840	100	100	38	40	7983	9028
45	165	5	120	1166	1325	1484	"120 to 250 ft"	0.38	0.36	-	10128	100	100	38	40	8208	9270
46	170	5	120	1170	1330	1490	"120 to 250 ft"	0.38	0.36	-	10416	100	100	38	40	8433	9511
47	175	5	120	1175	1335	1495	"120 to 250 ft"	0.38	0.36	-	10704	100	100	38	40	8658	9753
48	180	5	120	1179	1340	1501	"120 to 250 ft"	0.38	0.36	-	10992	100	100	38	40	8883	9995
49	185	5	120	1184	1345	1506	"120 to 250 ft"	0.38	0.36	-	11280	100	100	38	40	9108	10236
50	190	5	120	1188	1350	1512	"120 to 250 ft"	0.38	0.36	-	11568	100	100	38	40	9333	10478
51	195	5	120	1192	1355	1518	"120 to 250 ft"	0.38	0.36	-	11856	100	100	38	40	9558	10720
52	200	5	120	1197	1360	1523	"120 to 250 ft"	0.38	0.36	-	12144	100	100	38	40	9783	10961
53	205	5	120	1201	1365	1529	"120 to 250 ft"	0.38	0.36	-	12432	100	100	38	40	10008	11203
54	210	5	120	1206	1370	1534	"120 to 250 ft"	0.38	0.36	-	12720	100	100	38	40	10233	11445
55	215	5	120	1210	1375	1540	"120 to 250 ft"	0.38	0.36	-	13008	100	100	38	40	10458	11686
56	220	5	120	1214	1380	1546	"120 to 250 ft"	0.38	0.36	-	13296	100	100	38	40	10683	11928
57	225	5	120	1219	1385	1551	"120 to 250 ft"	0.38	0.36	-	13584	100	100	38	40	10908	12170
58	230	5	120	1223	1390	1557	"120 to 250 ft"	0.38	0.36	-	13872	100	100	38	40	11133	12411
59	235	5	120	1228	1395	1562	"120 to 250 ft"	0.38	0.36	-	14160	100	100	38	40	11358	12653
60	240	5	120	1232	1400	1568	"120 to 250 ft"	0.38	0.36	-	14448	100	100	38	40	11583	12895
61	245	5	120	1236	1405	1574	"120 to 250 ft"	0.38	0.36	-	14736	100	100	38	40	11808	13136
62	248.75	2.5	120	1241	1410	1579	"120 to 250 ft"	0.38	0.36	-	14952	100	100	38	40	11977	13317
			130	1500	1500	1500											

POLB - Zone I (Liquefied Condition)

				Shear Wave Velocity (ft/s)			Reference Curves			Shear strength Prameters						Equivalent Shear Strength (psf)	
Layer No.	Depth (ft) - Layer Middle	Layer Thickness (ft)	Unit Weight (pcf)		Liquefied Condition		G/Gmax and D/Dmax	LB ko		PI	Eff. Ver. Stress (psf)	LB Cohesion (psf)		LB Friction Angle (deg)		Lower Bound	
1	1.25	2.5	120		528		"0-20 ft"	0.47		-	150	50		32		300	
2	3.75	2.5	120		528		"0-20 ft"	0.47		-	450	50		32		487	
3	6.25	2.5	120		528		"0-20 ft"	0.47		-	750	50		32		675	
4	8.75	2.5	120		528		"0-20 ft"	0.47		-	1050	50		32		862	
5	11.25	2.5	120		233		Vucentic-Dobry	1.00		0	1272	228.3		0		228	
6	13.75	2.5	120		243		Vucentic-Dobry	1.00		0	1416	249.9		0		250	
7	16.25	2.5	120		253		Vucentic-Dobry	1.00		0	1560	271.5		0		272	
8	18.75	2.5	120		263		Vucentic-Dobry	1.00		0	1704	293.1		0		293	
9	21.25	2.5	120		272		Vucentic-Dobry	1.00		0	1848	314.7		0		315	
10	23.75	2.5	120		280		Vucentic-Dobry	1.00		0	1992	336.3		0		336	
11	26.25	2.5	120		289		Vucentic-Dobry	1.00		0	2136	357.9		0		358	
12	28.75	2.5	120		297		Vucentic-Dobry	1.00		0	2280	379.5		0		380	
13	31.25	2.5	120		305		Vucentic-Dobry	1.00		0	2424	401.1		0		401	
14	33.75	2.5	120		312		Vucentic-Dobry	1.00		0	2568	422.7		0		423	
15	36.25	2.5	120		320		Vucentic-Dobry	1.00		0	2712	444.3		0		444	
16	38.75	2.5	120		327		Vucentic-Dobry	1.00		0	2856	465.9		0		466	
17	41.25	2.5	120		704		"20 to 50 ft"	0.43		-	3000	100		35		2376	
18	43.75	2.5	120		704		"20 to 50 ft"	0.43		-	3144	100		35		2477	
19	46.25	2.5	120		704		"20 to 50 ft"	0.43		-	3288	100		35		2577	
20	48.75	2.5	120		704		"20 to 50 ft"	0.43		-	3432	100		35		2678	
21	51.25	2.5	120		704		"50 to 120 ft"	0.43		-	3576	100		35		2779	
22	53.75	2.5	120		704		"50 to 120 ft"	0.43		-	3720	100		35		2880	
23	56.25	2.5	120		704		"50 to 120 ft"	0.43		-	3864	100		35		2981	
24	60	5	120		704		"50 to 120 ft"	0.43		-	4080	100		35		3132	
25	65	5	120		704		"50 to 120 ft"	0.38		-	4368	100		38		3708	
26	70	5	120		730		"50 to 120 ft"	0.38		-	4656	100		38		3933	
27	75	5	120		757		"50 to 120 ft"	0.38		-	4944	100		38		4158	
28	80	5	120		783		"50 to 120 ft"	0.38		-	5232	100		38		4383	
29	85	5	120		810		"50 to 120 ft"	0.38		-	5520	100		38		4608	
30	90	5	120		836		"50 to 120 ft"	0.38		-	5808	100		38		4833	
31	95	5	120		862		"50 to 120 ft"	0.38		-	6096	100		38		5058	
32	100	5	120		889		"50 to 120 ft"	0.38		-	6384	100		38		5283	
33	105	5	120		915		"50 to 120 ft"	0.38		-	6672	100		38		5508	
34	110	5	120		942		"50 to 120 ft"	0.38		-	6960	100		38		5733	
35	115	5	120		968		"50 to 120 ft"	0.38		-	7248	100		38		5958	
36	120	5	120		994		"50 to 120 ft"	0.38		-	7536	100		38		6183	
37	125	5	120		1021		"120 to 250 ft"	0.38		-	7824	100		38		6408	
38	130	5	120		1047		"120 to 250 ft"	0.38		-	8112	100		38		6633	
39	135	5	120		1074		"120 to 250 ft"	0.38		-	8400	100		38		6858	
40	140	5	120		1100		"120 to 250 ft"	0.38		-	8688	100		38		7083	
41	145	5	120		1126		"120 to 250 ft"	0.38		-	8976	100		38		7308	
42	150	5	120		1153		"120 to 250 ft"	0.38		-	9264	100		38		7533	
43	155	5	120		1157		"120 to 250 ft"	0.38		-	9552	100		38		7758	
44	160	5	120		1162		"120 to 250 ft"	0.38		-	9840	100		38		7983	
45	165	5	120		1166		"120 to 250 ft"	0.38		-	10128	100		38		8208	
46	170	5	120		1170		"120 to 250 ft"	0.38		-	10416	100		38		8433	
47	175	5	120		1175		"120 to 250 ft"	0.38		-	10704	100		38		8658	
48	180	5	120		1179		"120 to 250 ft"	0.38		-	10992	100		38		8883	
49	185	5	120		1184		"120 to 250 ft"	0.38		-	11280	100		38		9108	
50	190	5	120		1188		"120 to 250 ft"	0.38		-	11568	100		38		9333	
51	195	5	120		1192		"120 to 250 ft"	0.38		-	11856	100		38		9558	
52	200	5	120		1197		"120 to 250 ft"	0.38		-	12144	100		38		9783	
53	205	5	120		1201		"120 to 250 ft"	0.38		-	12432	100		38		10008	
54	210	5	120		1206		"120 to 250 ft"	0.38		-	12720	100		38		10233	
55	215	5	120		1210		"120 to 250 ft"	0.38		-	13008	100		38		10458	
56	220	5	120		1214		"120 to 250 ft"	0.38		-	13296	100		38		10683	
57	225	5	120		1219		"120 to 250 ft"	0.38		-	13584	100		38		10908	
58	230	5	120		1223		"120 to 250 ft"	0.38		-	13872	100		38		11133	
59	235	5	120		1228		"120 to 250 ft"	0.38		-	14160	100		38		11358	
60	240	5	120		1232		"120 to 250 ft"	0.38		-	14448	100		38		11583	
61	245	5	120		1236		"120 to 250 ft"	0.38		-	14736	100		38		11808	
62	248.75	2.5	120		1241		"120 to 250 ft"	0.38		-	14952	100		38		11977	
			130		1500												

POLB - Zone II (Lower- and Upper-Bound Estimates of Soil Properties)

				Shear Wave Velocity (ft/s)			Reference Curves			Shear strength Prameters						Equivalent Shear Strength (psf)	
Layer No.	Depth (ft) - Layer Middle	Layer Thickness (ft)	Unit Weight (pcf)	Lower Bound	Baseline	Upper Bound	G/Gmax and D/Dmax	LB ko	UB ko	PI	Eff. Ver. Stress (psf)	LB Cohesion (psf)	UB Cohesion (psf)	LB Friction Angle (deg)	UB Friction Angle (deg)	Lower Bound	Upper Bound
1	1.25	2.5	120	528	600	672	"0-20 ft"	0.47	0.43	-	150	50	100	32	35	300	765
2	3.75	2.5	120	528	600	672	"0-20 ft"	0.47	0.43	-	450	50	100	32	35	487	975
3	6.25	2.5	120	528	600	672	"0-20 ft"	0.47	0.43	-	750	50	100	32	35	675	1185
4	8.75	2.5	120	528	600	672	"0-20 ft"	0.47	0.43	-	1050	50	100	32	35	862	1395
5	11.25	2.5	120	484	550	616	"0-20 ft"	0.47	0.43	-	1272	50	100	32	35	1001	1551
6	13.75	2.5	120	484	550	616	"0-20 ft"	0.47	0.43	-	1416	50	100	32	35	1091	1652
7	16.25	2.5	120	484	550	616	"0-20 ft"	0.47	0.43	-	1560	50	100	32	35	1181	1752
8	18.75	2.5	120	484	550	616	"0-20 ft"	0.47	0.43	-	1704	50	100	32	35	1271	1853
9	21.25	2.5	120	484	550	616	"20 to 50 ft"	0.47	0.43	-	1848	50	100	32	35	1361	1954
10	23.75	2.5	120	484	550	616	"20 to 50 ft"	0.47	0.43	-	1992	50	100	32	35	1451	2055
11	26.25	2.5	120	484	550	616	"20 to 50 ft"	0.47	0.43	-	2136	50	100	32	35	1541	2156
12	28.75	2.5	120	484	550	616	"20 to 50 ft"	0.47	0.43	-	2280	50	100	32	35	1631	2257
13	31.25	2.5	120	484	550	616	"20 to 50 ft"	0.47	0.43	-	2424	50	100	32	35	1721	2357
14	33.75	2.5	120	484	550	616	"20 to 50 ft"	0.47	0.43	-	2568	50	100	32	35	1811	2458
15	36.25	2.5	120	484	550	616	"20 to 50 ft"	0.47	0.43	-	2712	50	100	32	35	1901	2559
16	38.75	2.5	120	484	550	616	"20 to 50 ft"	0.47	0.43	-	2856	50	100	32	35	1991	2660
17	41.25	2.5	120	572	650	728	"20 to 50 ft"	0.47	0.43	-	3000	50	100	32	35	2081	2761
18	43.75	2.5	120	572	650	728	"20 to 50 ft"	0.47	0.43	-	3144	50	100	32	35	2171	2862
19	46.25	2.5	120	572	650	728	"20 to 50 ft"	0.47	0.43	-	3288	50	100	32	35	2261	2962
20	48.75	2.5	120	572	650	728	"20 to 50 ft"	0.47	0.43	-	3432	50	100	32	35	2351	3063
21	51.25	2.5	120	572	650	728	"50 to 120 ft"	0.47	0.43	-	3576	50	100	32	35	2441	3164
22	53.75	2.5	120	572	650	728	"50 to 120 ft"	0.47	0.43	-	3720	50	100	32	35	2531	3265
23	56.25	2.5	120	616	700	784	"50 to 120 ft"	0.47	0.43	-	3864	50	100	32	35	2621	3366
24	58.75	2.5	120	686	780	874	"50 to 120 ft"	0.43	0.38	-	4008	50	100	35	38	3031	3856
25	61.25	2.5	120	704	800	896	"50 to 120 ft"	0.43	0.38	-	4152	100	100	35	38	3182	3969
26	63.75	2.5	120	704	800	896	"50 to 120 ft"	0.43	0.38	-	4296	100	100	35	38	3283	4081
27	67.5	5	120	717	815	913	"50 to 120 ft"	0.43	0.38	-	4512	100	100	35	38	3434	4250
28	72.5	5	120	744	845	946	"50 to 120 ft"	0.43	0.38	-	4800	100	100	35	38	3636	4475
29	77.5	5	120	770	875	980	"50 to 120 ft"	0.43	0.38	-	5088	100	100	35	38	3838	4700
30	82.5	5	120	796	905	1014	"50 to 120 ft"	0.38	0.36	-	5376	100	100	38	40	4496	5282
31	87.5	5	120	823	935	1047	"50 to 120 ft"	0.38	0.36	-	5664	100	100	38	40	4721	5524
32	92.5	5	120	849	965	1081	"50 to 120 ft"	0.38	0.36	-	5952	100	100	38	40	4946	5766
33	97.5	5	120	876	995	1114	"50 to 120 ft"	0.38	0.36	-	6240	100	100	38	40	5171	6007
34	102.5	5	120	902	1025	1148	"50 to 120 ft"	0.38	0.36	-	6528	100	100	38	40	5396	6249
35	107.5	5	120	928	1055	1182	"50 to 120 ft"	0.38	0.36	-	6816	100	100	38	40	5621	6491
36	112.5	5	120	955	1085	1215	"50 to 120 ft"	0.38	0.36	-	7104	100	100	38	40	5846	6732
37	117.5	5	120	981	1115	1249	"50 to 120 ft"	0.38	0.36	-	7392	100	100	38	40	6071	6974
38	122.5	5	120	1008	1145	1282	"120 to 250 ft"	0.38	0.36	-	7680	100	100	38	40	6296	7216
39	127.5	5	120	1034	1175	1316	"120 to 250 ft"	0.38	0.36	-	7968	100	100	38	40	6521	7457
40	132.5	5	120	1060	1205	1350	"120 to 250 ft"	0.38	0.36	-	8256	100	100	38	40	6746	7699
41	137.5	5	120	1087	1235	1383	"120 to 250 ft"	0.38	0.36	-	8544	100	100	38	40	6971	7941
42	142.5	5	120	1113	1265	1417	"120 to 250 ft"	0.38	0.36	-	8832	100	100	38	40	7196	8182
43	147.5	5	120	1140	1295	1450	"120 to 250 ft"	0.38	0.36	-	9120	100	100	38	40	7421	8424
44	152.5	5	120	1155	1313	1470	"120 to 250 ft"	0.38	0.36	-	9408	100	100	38	40	7646	8666
45	157.5	5	120	1159	1318	1476	"120 to 250 ft"	0.38	0.36	-	9696	100	100	38	40	7871	8907
46	162.5	5	120	1164	1323	1481	"120 to 250 ft"	0.38	0.36	-	9984	100	100	38	40	8096	9149
47	167.5	5	120	1168	1328	1487	"120 to 250 ft"	0.38	0.36	-	10272	100	100	38	40	8321	9391
48	172.5	5	120	1173	1333	1492	"120 to 250 ft"	0.38	0.36	-	10560	100	100	38	40	8546	9632
49	177.5	5	120	1177	1338	1498	"120 to 250 ft"	0.38	0.36	-	10848	100	100	38	40	8771	9874
50	182.5	5	120	1181	1343	1504	"120 to 250 ft"	0.38	0.36	-	11136	100	100	38	40	8996	10115
51	187.5	5	120	1186	1348	1509	"120 to 250 ft"	0.38	0.36	-	11424	100	100	38	40	9221	10357
52	192.5	5	120	1190	1353	1515	"120 to 250 ft"	0.38	0.36	-	11712	100	100	38	40	9446	10599
53	197.5	5	120	1195	1358	1520	"120 to 250 ft"	0.38	0.36	-	12000	100	100	38	40	9671	10840
54	202.5	5	120	1199	1363	1526	"120 to 250 ft"	0.38	0.36	-	12288	100	100	38	40	9896	11082
55	207.5	5	120	1203	1368	1532	"120 to 250 ft"	0.38	0.36	-	12576	100	100	38	40	10121	11324
56	212.5	5	120	1208	1373	1537	"120 to 250 ft"	0.38	0.36	-	12864	100	100	38	40	10346	11565
57	217.5	5	120	1212	1378	1543	"120 to 250 ft"	0.38	0.36	-	13152	100	100	38	40	10571	11807
58	222.5	5	120	1217	1383	1548	"120 to 250 ft"	0.38	0.36	-	13440	100	100	38	40	10796	12049
59	227.5	5	120	1221	1388	1554	"120 to 250 ft"	0.38	0.36	-	13728	100	100	38	40	11021	12290
60	232.5	5	120	1225	1393	1560	"120 to 250 ft"	0.38	0.36	-	14016	100	100	38	40	11246	12532
61	237.5	5	120	1230	1398	1565	"120 to 250 ft"	0.38	0.36	-	14304	100	100	38	40	11471	12774
62	242.5	5	120	1234	1403	1571	"120 to 250 ft"	0.38	0.36	-	14592	100	100	38	40	11696	13015
63	246.25	2.5	120	1238	1407	1575	"120 to 250 ft"	0.38	0.36	-	14880	100	100	38	40	11865	13197
64	248.75	2.5	120	1241	1410	1579.2	"120 to 250 ft"	0.38	0.36	-	14952	100	100	38	40	11977	13317
			130	1500	1500	1500											

POLB - Zone II (Liquefied Condition)

				Shear Wave Velocity (ft/s)		Reference Curves					Shear strength Prameters					Equivalent Shear Strength (psf)	
Layer No.	Depth (ft) - Layer Middle	Layer Thickness (ft)	Unit Weight (pcf)		Liquefied Condition	G/Gmax and D/Dmax	LB ko		PI	Eff. Ver. Stress (psf)	LB Cohesion (psf)		LB Friction Angle (deg)		Liquefied Condition Strength		
1	1.25	2.5	120		528	"0-20 ft"	0.47		-	150	50		32		300		
2	3.75	2.5	120		528	"0-20 ft"	0.47		-	450	50		32		487		
3	6.25	2.5	120		528	"0-20 ft"	0.47		-	750	50		32		675		
4	8.75	2.5	120		528	"0-20 ft"	0.47		-	1050	50		32		862		
5	11.25	2.5	120		233	Vucentic-Dobry	1.00		0	1272	228.3		0		228		
6	13.75	2.5	120		243	Vucentic-Dobry	1.00		0	1416	249.9		0		250		
7	16.25	2.5	120		253	Vucentic-Dobry	1.00		0	1560	271.5		0		272		
8	18.75	2.5	120		263	Vucentic-Dobry	1.00		0	1704	293.1		0		293		
9	21.25	2.5	120		272	Vucentic-Dobry	1.00		0	1848	314.7		0		315		
10	23.75	2.5	120		280	Vucentic-Dobry	1.00		0	1992	336.3		0		336		
11	26.25	2.5	120		289	Vucentic-Dobry	1.00		0	2136	357.9		0		358		
12	28.75	2.5	120		297	Vucentic-Dobry	1.00		0	2280	379.5		0		380		
13	31.25	2.5	120		305	Vucentic-Dobry	1.00		0	2424	401.1		0		401		
14	33.75	2.5	120		312	Vucentic-Dobry	1.00		0	2568	422.7		0		423		
15	36.25	2.5	120		320	Vucentic-Dobry	1.00		0	2712	444.3		0		444		
16	38.75	2.5	120		327	Vucentic-Dobry	1.00		0	2856	465.9		0		466		
17	41.25	2.5	120		334	Vucentic-Dobry	1.00		0	3000	487.5		0		488		
18	43.75	2.5	120		341	Vucentic-Dobry	1.00		0	3144	509.1		0		509		
19	46.25	2.5	120		348	Vucentic-Dobry	1.00		0	3288	530.7		0		531		
20	48.75	2.5	120		355	Vucentic-Dobry	1.00		0	3432	552.3		0		552		
21	51.25	2.5	120		361	Vucentic-Dobry	1.00		0	3576	573.9		0		574		
22	53.75	2.5	120		367	Vucentic-Dobry	1.00		0	3720	595.5		0		596		
23	56.25	2.5	120		374	Vucentic-Dobry	1.00		0	3864	617.1		0		617		
24	58.75	2.5	120		380	Vucentic-Dobry	1.00		0	4008	638.7		0		639		
25	61.25	2.5	120		704	"50 to 120 ft"	0.43		-	4152	100		35		3182		
26	63.75	2.5	120		704	"50 to 120 ft"	0.43		-	4296	100		35		3283		
27	67.5	5	120		717	"50 to 120 ft"	0.43		-	4512	100		35		3434		
28	72.5	5	120		744	"50 to 120 ft"	0.43		-	4800	100		35		3636		
29	77.5	5	120		770	"50 to 120 ft"	0.43		-	5088	100		35		3838		
30	82.5	5	120		796	"50 to 120 ft"	0.38		-	5376	100		38		4496		
31	87.5	5	120		823	"50 to 120 ft"	0.38		-	5664	100		38		4721		
32	92.5	5	120		849	"50 to 120 ft"	0.38		-	5952	100		38		4946		
33	97.5	5	120		876	"50 to 120 ft"	0.38		-	6240	100		38		5171		
34	102.5	5	120		902	"50 to 120 ft"	0.38		-	6528	100		38		5396		
35	107.5	5	120		928	"50 to 120 ft"	0.38		-	6816	100		38		5621		
36	112.5	5	120		955	"120 to 250 ft"	0.38		-	7104	100		38		5846		
37	117.5	5	120		981	"120 to 250 ft"	0.38		-	7392	100		38		6071		
38	122.5	5	120		1008	"120 to 250 ft"	0.38		-	7680	100		38		6296		
39	127.5	5	120		1034	"120 to 250 ft"	0.38		-	7968	100		38		6521		
40	132.5	5	120		1060	"120 to 250 ft"	0.38		-	8256	100		38		6746		
41	137.5	5	120		1087	"120 to 250 ft"	0.38		-	8544	100		38		6971		
42	142.5	5	120		1113	"120 to 250 ft"	0.38		-	8832	100		38		7196		
43	147.5	5	120		1140	"120 to 250 ft"	0.38		-	9120	100		38		7421		
44	152.5	5	120		1155	"120 to 250 ft"	0.38		-	9408	100		38		7646		
45	157.5	5	120		1159	"120 to 250 ft"	0.38		-	9696	100		38		7871		
46	162.5	5	120		1164	"120 to 250 ft"	0.38		-	9984	100		38		8096		
47	167.5	5	120		1168	"120 to 250 ft"	0.38		-	10272	100		38		8321		
48	172.5	5	120		1173	"120 to 250 ft"	0.38		-	10560	100		38		8546		
49	177.5	5	120		1177	"120 to 250 ft"	0.38		-	10848	100		38		8771		
50	182.5	5	120		1181	"120 to 250 ft"	0.38		-	11136	100		38		8996		
51	187.5	5	120		1186	"120 to 250 ft"	0.38		-	11424	100		38		9221		
52	192.5	5	120		1190	"120 to 250 ft"	0.38		-	11712	100		38		9446		
53	197.5	5	120		1195	"120 to 250 ft"	0.38		-	12000	100		38		9671		
54	202.5	5	120		1199	"120 to 250 ft"	0.38		-	12288	100		38		9896		
55	207.5	5	120		1203	"120 to 250 ft"	0.38		-	12576	100		38		10121		
56	212.5	5	120		1208	"120 to 250 ft"	0.38		-	12864	100		38		10346		
57	217.5	5	120		1212	"120 to 250 ft"	0.38		-	13152	100		38		10571		
58	222.5	5	120		1217	"120 to 250 ft"	0.38		-	13440	100		38		10796		
59	227.5	5	120		1221	"120 to 250 ft"	0.38		-	13728	100		38		11021		
60	232.5	5	120		1225	"120 to 250 ft"	0.38		-	14016	100		38		11246		
61	237.5	5	120		1230	"120 to 250 ft"	0.38		-	14304	100		38		11471		
62	242.5	5	120		1234	"120 to 250 ft"	0.38		-	14592	100		38		11696		
63	246.25	2.5	120		1238	"120 to 250 ft"	0.38		-	14808	100		38		11865		
64	248.75	2.5	120		1241	"120 to 250 ft"	0.38		-	14952	100		38		11977		
			130		1500												

POLB - Zone III (Lower- and Upper-Bound Estimates of Soil Properties)

				Shear Wave Velocity (ft/s)			Reference Curves			Shear strength Prameters						Equivalent Shear Strength (psf)	
Layer No.	Depth (ft) - Layer Middle	Layer Thickness (ft)	Unit Weight (pcf)	Lower Bound	Baseline	Upper Bound	G/Gmax and D/Dmax	LB ko	UB ko	PI	Eff. Ver. Stress (psf)	LB Cohesion (psf)	UB Cohesion (psf)	LB Friction Angle (deg)	UB Friction Angle (deg)	Lower Bound	Upper Bound
1	1.25	2.5	120	528	600	672	"0-20 ft"	0.47	0.43	-	150	50	100	32	35	300	765
2	3.75	2.5	120	528	600	672	"0-20 ft"	0.47	0.43	-	450	50	100	32	35	487	975
3	6.25	2.5	120	528	600	672	"0-20 ft"	0.47	0.43	-	750	50	100	32	35	675	1185
4	8.75	2.5	120	528	600	672	"0-20 ft"	0.47	0.43	-	1050	50	100	32	35	862	1395
5	11.25	2.5	120	484	550	616	"0-20 ft"	0.47	0.43	-	1272	50	100	32	35	1001	1551
6	13.75	2.5	120	484	550	616	"0-20 ft"	0.47	0.43	-	1416	50	100	32	35	1091	1652
7	16.25	2.5	120	484	550	616	"0-20 ft"	0.47	0.43	-	1560	50	100	32	35	1181	1752
8	18.75	2.5	120	484	550	616	"0-20 ft"	0.47	0.43	-	1704	50	100	32	35	1271	1853
9	21.25	2.5	120	484	550	616	"20 to 50 ft"	0.47	0.43	-	1848	50	100	32	35	1361	1954
10	23.75	2.5	120	484	550	616	"20 to 50 ft"	0.47	0.43	-	1992	50	100	32	35	1451	2055
11	26.25	2.5	120	484	550	616	"20 to 50 ft"	0.47	0.43	-	2136	50	100	32	35	1541	2156
12	28.75	2.5	120	484	550	616	"20 to 50 ft"	0.47	0.43	-	2280	50	100	32	35	1631	2257
13	31.25	2.5	120	484	550	616	"20 to 50 ft"	0.47	0.43	-	2424	50	100	32	35	1721	2357
14	33.75	2.5	120	484	550	616	"20 to 50 ft"	0.47	0.43	-	2568	50	100	32	35	1811	2458
15	36.25	2.5	120	484	550	616	"20 to 50 ft"	0.47	0.43	-	2712	50	100	32	35	1901	2559
16	38.75	2.5	120	484	550	616	"20 to 50 ft"	0.47	0.43	-	2856	50	100	32	35	1991	2660
17	41.25	2.5	120	484	550	616	"20 to 50 ft"	0.47	0.43	-	3000	50	100	32	35	2081	2761
18	43.75	2.5	120	484	550	616	"20 to 50 ft"	0.47	0.43	-	3144	50	100	32	35	2171	2862
19	46.25	2.5	120	704	800	896	"20 to 50 ft"	0.47	0.43	-	3288	50	100	32	35	2261	2962
20	48.75	2.5	120	704	800	896	"20 to 50 ft"	0.47	0.43	-	3432	50	100	32	35	2351	3063
21	51.25	2.5	120	704	800	896	"50 to 120 ft"	0.47	0.43	-	3576	50	100	32	35	2441	3164
22	53.75	2.5	120	704	800	896	"50 to 120 ft"	0.47	0.43	-	3720	50	100	32	35	2531	3265
23	56.25	2.5	120	704	800	896	"50 to 120 ft"	0.47	0.43	-	3864	50	100	32	35	2621	3366
24	58.75	2.5	120	704	800	896	"50 to 120 ft"	0.47	0.43	-	4008	50	100	32	35	2711	3467
25	61.25	2.5	110	528	600	672	Vucentic-Dobry	1.00	1.00	20L to 50U	4139.5	1000	2500	0	0	1000	2500
26	63.75	2.5	110	528	600	672	Vucentic-Dobry	1.00	1.00	20L to 50U	4258.5	1000	2500	0	0	1000	2500
27	66.25	2.5	120	713	810	907	"50 to 120 ft"	0.43	0.38	-	4390	100	100	35	38	3349	4155
28	68.75	2.5	120	724	823	921	"50 to 120 ft"	0.43	0.38	-	4534	100	100	35	38	3450	4267
29	71.25	2.5	120	737	838	938	"50 to 120 ft"	0.43	0.38	-	4678	100	100	35	38	3551	4380
30	73.75	2.5	120	750	853	955	"50 to 120 ft"	0.43	0.38	-	4822	100	100	35	38	3651	4492
31	76.25	2.5	120	763	868	972	"50 to 120 ft"	0.43	0.38	-	4966	100	100	35	38	3752	4605
32	78.75	2.5	120	777	883	988	"50 to 120 ft"	0.43	0.38	-	5110	100	100	35	38	3853	4717
33	81.25	2.5	120	790	898	1005	"50 to 120 ft"	0.38	0.36	-	5254	100	100	38	40	4400	5180
34	85	5	120	810	920	1030	"50 to 120 ft"	0.38	0.36	-	5470	100	100	38	40	4569	5361
35	90	5	120	836	950	1064	"50 to 120 ft"	0.38	0.36	-	5758	100	100	38	40	4794	5603
36	95	5	120	862	980	1098	"50 to 120 ft"	0.38	0.36	-	6046	100	100	38	40	5019	5844
37	100	5	120	889	1010	1131	"50 to 120 ft"	0.38	0.36	-	6334	100	100	38	40	5244	6086
38	105	5	120	915	1040	1165	"50 to 120 ft"	0.38	0.36	-	6622	100	100	38	40	5469	6328
39	110	5	120	942	1070	1198	"50 to 120 ft"	0.38	0.36	-	6910	100	100	38	40	5694	6569
40	115	5	120	968	1100	1232	"50 to 120 ft"	0.38	0.36	-	7198	100	100	38	40	5919	6811
41	120	5	120	994	1130	1266	"50 to 120 ft"	0.38	0.36	-	7486	100	100	38	40	6144	7053
42	125	5	120	1021	1160	1299	"120 to 250 ft"	0.38	0.36	-	7774	100	100	38	40	6369	7294
43	130	5	120	1047	1190	1333	"120 to 250 ft"	0.38	0.36	-	8062	100	100	38	40	6594	7536
44	135	5	120	1074	1220	1366	"120 to 250 ft"	0.38	0.36	-	8350	100	100	38	40	6819	7778
45	140	5	120	1100	1250	1400	"120 to 250 ft"	0.38	0.36	-	8638	100	100	38	40	7044	8019
46	145	5	120	1126	1280	1434	"120 to 250 ft"	0.38	0.36	-	8926	100	100	38	40	7269	8261
47	150	5	120	1147	1304	1460	"120 to 250 ft"	0.38	0.36	-	9214	100	100	38	40	7494	8503
48	155	5	120	1157	1315	1473	"120 to 250 ft"	0.38	0.36	-	9502	100	100	38	40	7719	8744
49	160	5	120	1162	1320	1478	"120 to 250 ft"	0.38	0.36	-	9790	100	100	38	40	7944	8986
50	165	5	120	1166	1325	1484	"120 to 250 ft"	0.38	0.36	-	10078	100	100	38	40	8169	9228
51	170	5	120	1170	1330	1490	"120 to 250 ft"	0.38	0.36	-	10366	100	100	38	40	8394	9469
52	175	5	120	1175	1335	1495	"120 to 250 ft"	0.38	0.36	-	10654	100	100	38	40	8619	9711
53	180	5	120	1179	1340	1501	"120 to 250 ft"	0.38	0.36	-	10942	100	100	38	40	8844	9953
54	185	5	120	1184	1345	1506	"120 to 250 ft"	0.38	0.36	-	11230	100	100	38	40	9069	10194
55	190	5	120	1188	1350	1512	"120 to 250 ft"	0.38	0.36	-	11518	100	100	38	40	9294	10436
56	195	5	120	1192	1355	1518	"120 to 250 ft"	0.38	0.36	-	11806	100	100	38	40	9519	10678
57	200	5	120	1197	1360	1523	"120 to 250 ft"	0.38	0.36	-	12094	100	100	38	40	9744	10919
58	205	5	120	1201	1365	1529	"120 to 250 ft"	0.38	0.36	-	12382	100	100	38	40	9969	11161
59	210	5	120	1206	1370	1534	"120 to 250 ft"	0.38	0.36	-	12670	100	100	38	40	10194	11403
60	215	5	120	1210	1375	1540	"120 to 250 ft"	0.38	0.36	-	12958	100	100	38	40	10419	11644
61	220	5	120	1214	1380	1546	"120 to 250 ft"	0.38	0.36	-	13246	100	100	38	40	10644	11886
62	225	5	120	1219	1385	1551	"120 to 250 ft"	0.38	0.36	-	13534	100	100	38	40	10869	12128
63	230	5	120	1223	1390	1557	"120 to 250 ft"	0.38	0.36	-	13822	100	100	38	40	11094	12369
64	235	5	120	1228	1395	1562	"120 to 250 ft"	0.38	0.36	-	14110	100	100	38	40	11319	12611
65	240	5	120	1232	1400	1568	"120 to 250 ft"	0.38	0.36	-	14398	100	100	38	40	11544	12853
66	245	5	120	1237	1405	1574	"120 to 250 ft"	0.38	0.36	-	14686	100	100	38	40	11769	13094
67	248.75	2.5	120	1241	1410	1579.2	"120 to 250 ft"	0.38	0.36	-	14902	100	100	38	40	11938	13276
			130	1500	1500	1500											

POLB - Zone III (Liquefied Condition)

				Shear Wave Velocity (ft/s)			Reference Curves			Shear strength Prameters						Equivalent Shear Strength (psf)	
Layer No.	Depth (ft) - Layer Middle	Layer Thickness (ft)	Unit Weight (pcf)		Liquefied Condition		G/Gmax and D/Dmax	LB ko		PI	Eff. Ver. Stress (psf)	LB Cohesion (psf)		LB Friction Angle (deg)		Liquefied Condition Strength	
1	1.25	2.5	120		528		"0-20 ft"	0.47		-	150	50		32		300	
2	3.75	2.5	120		528		"0-20 ft"	0.47		-	450	50		32		487	
3	6.25	2.5	120		528		"0-20 ft"	0.47		-	750	50		32		675	
4	8.75	2.5	120		528		"0-20 ft"	0.47		-	1050	50		32		862	
5	11.25	2.5	120		233		Vucentic-Dobry	1.00	0	1272	228.3		0			228	
6	13.75	2.5	120		243		Vucentic-Dobry	1.00	0	1416	249.9		0			250	
7	16.25	2.5	120		253		Vucentic-Dobry	1.00	0	1560	271.5		0			272	
8	18.75	2.5	120		263		Vucentic-Dobry	1.00	0	1704	293.1		0			293	
9	21.25	2.5	120		272		Vucentic-Dobry	1.00	0	1848	314.7		0			315	
10	23.75	2.5	120		280		Vucentic-Dobry	1.00	0	1992	336.3		0			336	
11	26.25	2.5	120		289		Vucentic-Dobry	1.00	0	2136	357.9		0			358	
12	28.75	2.5	120		297		Vucentic-Dobry	1.00	0	2280	379.5		0			380	
13	31.25	2.5	120		305		Vucentic-Dobry	1.00	0	2424	401.1		0			401	
14	33.75	2.5	120		312		Vucentic-Dobry	1.00	0	2568	422.7		0			423	
15	36.25	2.5	120		320		Vucentic-Dobry	1.00	0	2712	444.3		0			444	
16	38.75	2.5	120		327		Vucentic-Dobry	1.00	0	2856	465.9		0			466	
17	41.25	2.5	120		334		Vucentic-Dobry	1.00	0	3000	487.5		0			488	
18	43.75	2.5	120		341		Vucentic-Dobry	1.00	0	3144	509.1		0			509	
19	46.25	2.5	120		348		Vucentic-Dobry	1.00	0	3288	530.7		0			531	
20	48.75	2.5	120		355		Vucentic-Dobry	1.00	0	3432	552.3		0			552	
21	51.25	2.5	120		361		Vucentic-Dobry	1.00	0	3576	573.9		0			574	
22	53.75	2.5	120		367		Vucentic-Dobry	1.00	0	3720	595.5		0			596	
23	56.25	2.5	120		374		Vucentic-Dobry	1.00	0	3864	617.1		0			617	
24	58.75	2.5	120		380		Vucentic-Dobry	1.00	0	4008	638.7		0			639	
25	61.25	2.5	110		528		Vucentic-Dobry	1.00	15	4139.5	1000		0			1000	
26	63.75	2.5	110		528		Vucentic-Dobry	1.00	15	4258.5	1000		0			1000	
27	66.25	2.5	120		713		"50 to 120 ft"	0.43	-	4390	100		35			3349	
28	68.75	2.5	120		724		"50 to 120 ft"	0.43	-	4534	100		35			3450	
29	71.25	2.5	120		737		"50 to 120 ft"	0.43	-	4678	100		35			3551	
30	73.75	2.5	120		750		"50 to 120 ft"	0.43	-	4822	100		35			3651	
31	76.25	2.5	120		763		"50 to 120 ft"	0.43	-	4966	100		35			3752	
32	78.75	2.5	120		777		"50 to 120 ft"	0.43	-	5110	100		35			3853	
33	81.25	2.5	120		790		"50 to 120 ft"	0.38	-	5254	100		38			4400	
34	85	5	120		810		"50 to 120 ft"	0.38	-	5470	100		38			4569	
35	90	5	120		836		"50 to 120 ft"	0.38	-	5758	100		38			4794	
36	95	5	120		862		"50 to 120 ft"	0.38	-	6046	100		38			5019	
37	100	5	120		889		"50 to 120 ft"	0.38	-	6334	100		38			5244	
38	105	5	120		915		"50 to 120 ft"	0.38	-	6622	100		38			5469	
39	110	5	120		942		"50 to 120 ft"	0.38	-	6910	100		38			5694	
40	115	5	120		968		"50 to 120 ft"	0.38	-	7198	100		38			5919	
41	120	5	120		994		"50 to 120 ft"	0.38	-	7486	100		38			6144	
42	125	5	120		1021		"120 to 250 ft"	0.38	-	7774	100		38			6369	
43	130	5	120		1047		"120 to 250 ft"	0.38	-	8062	100		38			6594	
44	135	5	120		1074		"120 to 250 ft"	0.38	-	8350	100		38			6819	
45	140	5	120		1100		"120 to 250 ft"	0.38	-	8638	100		38			7044	
46	145	5	120		1126		"120 to 250 ft"	0.38	-	8926	100		38			7269	
47	150	5	120		1147		"120 to 250 ft"	0.38	-	9214	100		38			7494	
48	155	5	120		1157		"120 to 250 ft"	0.38	-	9502	100		38			7719	
49	160	5	120		1162		"120 to 250 ft"	0.38	-	9790	100		38			7944	
50	165	5	120		1166		"120 to 250 ft"	0.38	-	10078	100		38			8169	
51	170	5	120		1170		"120 to 250 ft"	0.38	-	10366	100		38			8394	
52	175	5	120		1175		"120 to 250 ft"	0.38	-	10654	100		38			8619	
53	180	5	120		1179		"120 to 250 ft"	0.38	-	10942	100		38			8844	
54	185	5	120		1184		"120 to 250 ft"	0.38	-	11230	100		38			9069	
55	190	5	120		1188		"120 to 250 ft"	0.38	-	11518	100		38			9294	
56	195	5	120		1192		"120 to 250 ft"	0.38	-	11806	100		38			9519	
57	200	5	120		1197		"120 to 250 ft"	0.38	-	12094	100		38			9744	
58	205	5	120		1201		"120 to 250 ft"	0.38	-	12382	100		38			9969	
59	210	5	120		1206		"120 to 250 ft"	0.38	-	12670	100		38			10194	
60	215	5	120		1210		"120 to 250 ft"	0.38	-	12958	100		38			10419	
61	220	5	120		1214		"120 to 250 ft"	0.38	-	13246	100		38			10644	
62	225	5	120		1219		"120 to 250 ft"	0.38	-	13534	100		38			10869	
63	230	5	120		1223		"120 to 250 ft"	0.38	-	13822	100		38			11094	
64	235	5	120		1228		"120 to 250 ft"	0.38	-	14110	100		38			11319	
65	240	5	120		1232		"120 to 250 ft"	0.38	-	14398	100		38			11544	
66	245	5	120		1237		"120 to 250 ft"	0.38	-	14686	100		38			11769	
67	248.75	2.5	120		1241		"120 to 250 ft"	0.38	-	14902	100		38			11938	
			130		1500												

POLB - Zone IV (Lower- and Upper-Bound Estimates of Soil Properties)

				Shear Wave Velocity (ft/s)			Reference Curves			Shear strength Prameters						Equivalent Shear Strength (psf)	
Layer No.	Depth (ft) - Layer Middle	Layer Thickness (ft)	Unit Weight (pcf)	Lower Bound	Baseline	Upper Bound	G/Gmax and D/Dmax	LB ko	UB ko	PI	Eff. Ver. Stress (psf)		Cohesion (psf)	LB Friction Angle (deg)	UB Friction Angle (deg)	Lower Bound	Upper Bound
1	1.25	2.5	120	528	600	672	"0-20 ft"	0.47	0.43	-	150	50	100	32	35	300	765
2	3.75	2.5	120	528	600	672	"0-20 ft"	0.47	0.43	-	450	50	100	32	35	487	975
3	6.25	2.5	120	528	600	672	"0-20 ft"	0.47	0.43	-	750	50	100	32	35	675	1185
4	8.75	2.5	120	528	600	672	"0-20 ft"	0.47	0.43	-	1050	50	100	32	35	862	1395
5	11.25	2.5	120	484	550	616	"0-20 ft"	0.47	0.43	-	1272	50	100	32	35	1001	1551
6	13.75	2.5	120	484	550	616	"0-20 ft"	0.47	0.43	-	1416	50	100	32	35	1091	1652
7	16.25	2.5	120	484	550	616	"0-20 ft"	0.47	0.43	-	1560	50	100	32	35	1181	1752
8	18.75	2.5	120	484	550	616	"0-20 ft"	0.47	0.43	-	1704	50	100	32	35	1271	1853
9	21.25	2.5	120	484	550	616	"20 to 50 ft"	0.47	0.43	-	1848	50	100	32	35	1361	1954
10	23.75	2.5	120	484	550	616	"20 to 50 ft"	0.47	0.43	-	1992	50	100	32	35	1451	2055
11	26.25	2.5	120	484	550	616	"20 to 50 ft"	0.47	0.43	-	2136	50	100	32	35	1541	2156
12	28.75	2.5	120	484	550	616	"20 to 50 ft"	0.47	0.43	-	2280	50	100	32	35	1631	2257
13	31.25	2.5	120	484	550	616	"20 to 50 ft"	0.47	0.43	-	2424	50	100	32	35	1721	2357
14	33.75	2.5	120	484	550	616	"20 to 50 ft"	0.47	0.43	-	2568	50	100	32	35	1811	2458
15	36.25	2.5	120	484	550	616	"20 to 50 ft"	0.47	0.43	-	2712	50	100	32	35	1901	2559
16	38.75	2.5	120	484	550	616	"20 to 50 ft"	0.47	0.43	-	2856	50	100	32	35	1991	2660
17	41.25	2.5	120	484	550	616	"20 to 50 ft"	0.47	0.43	-	3000	50	100	32	35	2081	2761
18	43.75	2.5	120	484	550	616	"20 to 50 ft"	0.47	0.43	-	3144	50	100	32	35	2171	2862
19	46.25	2.5	120	704	800	896	"20 to 50 ft"	0.47	0.43	-	3288	50	100	32	35	2261	2962
20	48.75	2.5	120	704	800	896	"20 to 50 ft"	0.47	0.43	-	3432	50	100	32	35	2351	3063
21	51.25	2.5	120	704	800	896	"50 to 120 ft"	0.47	0.43	-	3576	50	100	32	35	2441	3164
22	53.75	2.5	120	704	800	896	"50 to 120 ft"	0.47	0.43	-	3720	50	100	32	35	2531	3265
23	56.25	2.5	120	704	800	896	"50 to 120 ft"	0.47	0.43	-	3864	50	100	32	35	2621	3366
24	58.75	2.5	120	704	800	896	"50 to 120 ft"	0.47	0.43	-	4008	50	100	32	35	2711	3467
25	61.25	2.5	110	528	600	672	Vucentic - Dobry	1.00	1.00	15	4139.5	1000	2500	0	0	1000	2500
26	63.75	2.5	110	528	600	672	Vucentic - Dobry	1.00	1.00	15	4258.5	1000	2500	0	0	1000	2500
27	66.25	2.5	120	792	900	1008	"50 to 120 ft"	0.43	0.38	-	4390	100	100	35	38	3349	4155
28	68.75	2.5	120	792	900	1008	"50 to 120 ft"	0.43	0.38	-	4534	100	100	35	38	3450	4267
29	71.25	2.5	120	792	900	1008	"50 to 120 ft"	0.43	0.38	-	4678	100	100	35	38	3551	4380
30	73.75	2.5	120	792	900	1008	"50 to 120 ft"	0.43	0.38	-	4822	100	100	35	38	3651	4492
31	76.25	2.5	120	792	900	1008	"50 to 120 ft"	0.43	0.38	-	4966	100	100	35	38	3752	4605
32	78.75	2.5	120	792	900	1008	"50 to 120 ft"	0.43	0.38	-	5110	100	100	35	38	3853	4717
33	81.25	2.5	120	792	900	1008	"50 to 120 ft"	0.43	0.38	-	5254	100	100	35	38	3954	4830
34	83.75	2.5	120	792	900	1008	"50 to 120 ft"	0.43	0.38	-	5398	100	100	35	38	4055	4942
35	86.25	2.5	120	816	927.5	1038.8	"50 to 120 ft"	0.38	0.36	-	5542	100	100	38	40	4625	5422
36	90	5	120	836	950	1064	"50 to 120 ft"	0.38	0.36	-	5758	100	100	38	40	4794	5603
37	95	5	120	862	980	1097.6	"50 to 120 ft"	0.38	0.36	-	6046	100	100	38	40	5019	5844
38	100	5	120	889	1010	1131.2	"50 to 120 ft"	0.38	0.36	-	6334	100	100	38	40	5244	6086
39	105	5	120	915	1040	1164.8	"50 to 120 ft"	0.38	0.36	-	6622	100	100	38	40	5469	6328
40	110	5	120	942	1070	1198.4	"50 to 120 ft"	0.38	0.36	-	6910	100	100	38	40	5694	6569
41	115	5	120	968	1100	1232	"50 to 120 ft"	0.38	0.36	-	7198	100	100	38	40	5919	6811
42	120	5	120	994	1130	1265.6	"50 to 120 ft"	0.38	0.36	-	7486	100	100	38	40	6144	7053
43	125	5	120	1021	1160	1299.2	"120 to 250 ft"	0.38	0.36	-	7774	100	100	38	40	6369	7294
44	130	5	120	1047	1190	1332.8	"120 to 250 ft"	0.38	0.36	-	8062	100	100	38	40	6594	7536
45	135	5	120	1074	1220	1366.4	"120 to 250 ft"	0.38	0.36	-	8350	100	100	38	40	6819	7778
46	140	5	120	1100	1250	1400	"120 to 250 ft"	0.38	0.36	-	8638	100	100	38	40	7044	8019
47	145	5	120	1126	1280	1433.6	"120 to 250 ft"	0.38	0.36	-	8926	100	100	38	40	7269	8261
48	150	5	120	1153	1310	1467.2	"120 to 250 ft"	0.38	0.36	-	9214	100	100	38	40	7494	8503
49	155	5	120	1157	1315	1472.8	"120 to 250 ft"	0.38	0.36	-	9502	100	100	38	40	7719	8744
50	160	5	120	1162	1320	1478.4	"120 to 250 ft"	0.38	0.36	-	9790	100	100	38	40	7944	8986
51	165	5	120	1166	1325	1484	"120 to 250 ft"	0.38	0.36	-	10078	100	100	38	40	8169	9228
52	170	5	120	1170	1330	1489.6	"120 to 250 ft"	0.38	0.36	-	10366	100	100	38	40	8394	9469
53	175	5	120	1175	1335	1495.2	"120 to 250 ft"	0.38	0.36	-	10654	100	100	38	40	8619	9711
54	180	5	120	1179	1340	1500.8	"120 to 250 ft"	0.38	0.36	-	10942	100	100	38	40	8844	9953
55	185	5	120	1184	1345	1506.4	"120 to 250 ft"	0.38	0.36	-	11230	100	100	38	40	9069	10194
56	190	5	120	1188	1350	1512	"120 to 250 ft"	0.38	0.36	-	11518	100	100	38	40	9294	10436
57	195	5	120	1192	1355	1517.6	"120 to 250 ft"	0.38	0.36	-	11806	100	100	38	40	9519	10678
58	200	5	120	1197	1360	1523.2	"120 to 250 ft"	0.38	0.36	-	12094	100	100	38	40	9744	10919
59	205	5	120	1201	1365	1528.8	"120 to 250 ft"	0.38	0.36	-	12382	100	100	38	40	9969	11161
60	210	5	120	1206	1370	1534.4	"120 to 250 ft"	0.38	0.36	-	12670	100	100	38	40	10194	11403
61	215	5	120	1210	1375	1540	"120 to 250 ft"	0.38	0.36	-	12958	100	100	38	40	10419	11644
62	220	5	120	1214	1380	1545.6	"120 to 250 ft"	0.38	0.36	-	13246	100	100	38	40	10644	11886
63	225	5	120	1219	1385	1551.2	"120 to 250 ft"	0.38	0.36	-	13534	100	100	38	40	10869	12128
64	230	5	120	1223	1390	1556.8	"120 to 250 ft"	0.38	0.36	-	13822	100	100	38	40	11094	12369
65	235	5	120	1228	1395	1562.4	"120 to 250 ft"	0.38	0.36	-	14110	100	100	38	40	11319	12611
66	240	5	120	1232	1400	1568	"120 to 250 ft"	0.38	0.36	-	14398	100	100	38	40	11544	12853
67	245	5	120	1236	1405	1573.6	"120 to 250 ft"	0.38	0.36	-	14686	100	100	38	40	11769	13094
68	248.75	2.5	120	1241	1410	1579.2	"120 to 250 ft"	0.38	0.36	-	14902	100	100	38	40	11938	13276
			130	1500	1500	1500											

POLB - Zone IV (Liquefied Condition)

				Shear Wave Velocity (ft/s)			Reference Curves				Shear strength Prameters						Equivalent Shear Strength (psf)	
Layer No.	Depth (ft) - Layer Middle	Layer Thickness (ft)	Unit Weight (pcf)		Liquefied Condition		G/Gmax and D/Dmax	LB ko		PI	Eff. Ver. Stress (psf)	LB Cohesion (psf)		LB Friction Angle (deg)		Liquefied Condition Strength		
1	1.25	2.5	120		528		"0-20 ft"	0.47		-	150	50		32		300		
2	3.75	2.5	120		528		"0-20 ft"	0.47		-	450	50		32		487		
3	6.25	2.5	120		528		"0-20 ft"	0.47		-	750	50		32		675		
4	8.75	2.5	120		528		"0-20 ft"	0.47		-	1050	50		32		862		
5	11.25	2.5	120		233		"0-20 ft"	1.00	0	1272	228.3		0			228		
6	13.75	2.5	120		243		"0-20 ft"	1.00	0	1416	249.9		0			250		
7	16.25	2.5	120		253		"0-20 ft"	1.00	0	1560	271.5		0			272		
8	18.75	2.5	120		263		"0-20 ft"	1.00	0	1704	293.1		0			293		
9	21.25	2.5	120		272		"20 to 50 ft"	1.00	0	1848	314.7		0			315		
10	23.75	2.5	120		280		"20 to 50 ft"	1.00	0	1992	336.3		0			336		
11	26.25	2.5	120		289		"20 to 50 ft"	1.00	0	2136	357.9		0			358		
12	28.75	2.5	120		297		"20 to 50 ft"	1.00	0	2280	379.5		0			380		
13	31.25	2.5	120		305		"20 to 50 ft"	1.00	0	2424	401.1		0			401		
14	33.75	2.5	120		312		"20 to 50 ft"	1.00	0	2568	422.7		0			423		
15	36.25	2.5	120		320		"20 to 50 ft"	1.00	0	2712	444.3		0			444		
16	38.75	2.5	120		327		"20 to 50 ft"	1.00	0	2856	465.9		0			466		
17	41.25	2.5	120		334		"20 to 50 ft"	1.00	0	3000	487.5		0			488		
18	43.75	2.5	120		341		"20 to 50 ft"	1.00	0	3144	509.1		0			509		
19	46.25	2.5	120		348		"20 to 50 ft"	1.00	0	3288	530.7		0			531		
20	48.75	2.5	120		355		"20 to 50 ft"	1.00	0	3432	552.3		0			552		
21	51.25	2.5	120		361		"50 to 120 ft"	1.00	0	3576	573.9		0			574		
22	53.75	2.5	120		367		"50 to 120 ft"	1.00	0	3720	595.5		0			596		
23	56.25	2.5	120		374		"50 to 120 ft"	1.00	0	3864	617.1		0			617		
24	58.75	2.5	120		380		"50 to 120 ft"	1.00	0	4008	638.7		0			639		
25	61.25	2.5	110		528		Vucentic-Dobry	1.00	15	4139.5	1000		0			1000		
26	63.75	2.5	110		528		Vucentic-Dobry	1.00	15	4258.5	1000		0			1000		
27	66.25	2.5	120		792		"50 to 120 ft"	0.43	-	4390	100		35			3349		
28	68.75	2.5	120		792		"50 to 120 ft"	0.43	-	4534	100		35			3450		
29	71.25	2.5	120		792		"50 to 120 ft"	0.43	-	4678	100		35			3551		
30	73.75	2.5	120		792		"50 to 120 ft"	0.43	-	4822	100		35			3651		
31	76.25	2.5	120		792		"50 to 120 ft"	0.43	-	4966	100		35			3752		
32	78.75	2.5	120		792		"50 to 120 ft"	0.43	-	5110	100		35			3853		
33	81.25	2.5	120		792		"50 to 120 ft"	0.43	-	5254	100		35			3954		
34	83.75	2.5	120		792		"50 to 120 ft"	0.43	-	5398	100		35			4055		
35	86.25	2.5	120		816		"50 to 120 ft"	0.38	-	5542	100		38			4625		
36	90	5	120		836		"50 to 120 ft"	0.38	-	5758	100		38			4794		
37	95	5	120		862		"50 to 120 ft"	0.38	-	6046	100		38			5019		
38	100	5	120		889		"50 to 120 ft"	0.38	-	6334	100		38			5244		
39	105	5	120		915		"50 to 120 ft"	0.38	-	6622	100		38			5469		
40	110	5	120		942		"50 to 120 ft"	0.38	-	6910	100		38			5694		
41	115	5	120		968		"50 to 120 ft"	0.38	-	7198	100		38			5919		
42	120	5	120		994		"50 to 120 ft"	0.38	-	7486	100		38			6144		
43	125	5	120		1021		"120 to 250 ft"	0.38	-	7774	100		38			6369		
44	130	5	120		1047		"120 to 250 ft"	0.38	-	8062	100		38			6594		
45	135	5	120		1074		"120 to 250 ft"	0.38	-	8350	100		38			6819		
46	140	5	120		1100		"120 to 250 ft"	0.38	-	8638	100		38			7044		
47	145	5	120		1126		"120 to 250 ft"	0.38	-	8926	100		38			7269		
48	150	5	120		1153		"120 to 250 ft"	0.38	-	9214	100		38			7494		
49	155	5	120		1157		"120 to 250 ft"	0.38	-	9502	100		38			7719		
50	160	5	120		1162		"120 to 250 ft"	0.38	-	9790	100		38			7944		
51	165	5	120		1166		"120 to 250 ft"	0.38	-	10078	100		38			8169		
52	170	5	120		1170		"120 to 250 ft"	0.38	-	10366	100		38			8394		
53	175	5	120		1175		"120 to 250 ft"	0.38	-	10654	100		38			8619		
54	180	5	120		1179		"120 to 250 ft"	0.38	-	10942	100		38			8844		
55	185	5	120		1184		"120 to 250 ft"	0.38	-	11230	100		38			9069		
56	190	5	120		1188		"120 to 250 ft"	0.38	-	11518	100		38			9294		
57	195	5	120		1192		"120 to 250 ft"	0.38	-	11806	100		38			9519		
58	200	5	120		1197		"120 to 250 ft"	0.38	-	12094	100		38			9744		
59	205	5	120		1201		"120 to 250 ft"	0.38	-	12382	100		38			9969		
60	210	5	120		1206		"120 to 250 ft"	0.38	-	12670	100		38			10194		
61	215	5	120		1210		"120 to 250 ft"	0.38	-	12958	100		38			10419		
62	220	5	120		1214		"120 to 250 ft"	0.38	-	13246	100		38			10644		
63	225	5	120		1219		"120 to 250 ft"	0.38	-	13534	100		38			10869		
64	230	5	120		1223		"120 to 250 ft"	0.38	-	13822	100		38			11094		
65	235	5	120		1228		"120 to 250 ft"	0.38	-	14110	100		38			11319		
66	240	5	120		1232		"120 to 250 ft"	0.38	-	14398	100		38			11544		
67	245	5	120		1236		"120 to 250 ft"	0.38	-	14686	100		38			11769		
68	248.75	2.5	120		1241		"120 to 250 ft"	0.38	-	14902	100		38			11938		
			130		1500													

G/Gmax amd Damping Curves based on EPRI (1993)

	G/Gmax	Damping (%)
Strain - %	0 to 20 ft	0 to 20 ft
0.0001	1.0000	0.3600
0.0003	1.0000	0.5467
0.001	0.9800	1.2000
0.003	0.9200	2.1000
0.01	0.7500	4.2000
0.03	0.5200	7.6000
0.1	0.2700	14.5000
0.3	0.1200	22.0000
1	0.0420	27.0000
3	0.0190	30.3000
10	0.0070	33.3000

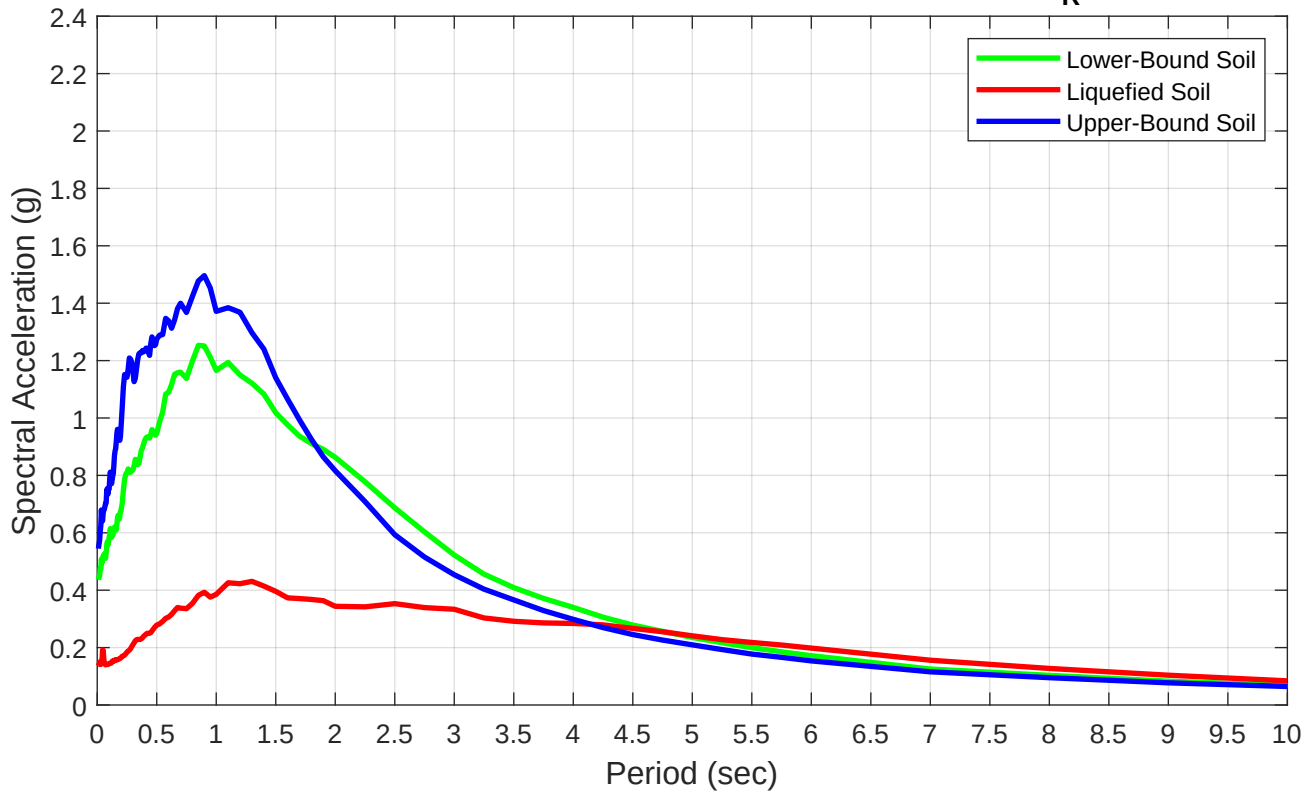
	G/Gmax	Damping (%)
Strain - %	50 to 120 ft	50 to 120 ft
0.0001	1.0000	0.2400
0.0003	1.0000	0.3644
0.001	1.0000	0.8000
0.003	0.9800	1.4000
0.01	0.8700	2.8000
0.03	0.6900	5.1000
0.1	0.4300	10.0000
0.3	0.2300	16.5000
1	0.0900	22.9000
3	0.0460	26.8000
10	0.0240	30.2000

	G/Gmax	Damping (%)
Strain - %	20 to 50 ft	20 to 50 ft
0.0001	1.0000	0.3000
0.0003	1.0000	0.4556
0.001	0.9900	1.0000
0.003	0.9500	1.7000
0.01	0.8200	3.4000
0.03	0.6100	6.1000
0.1	0.3600	12.0000
0.3	0.1700	19.1000
1	0.0610	24.9000
3	0.0280	28.5000
10	0.0120	31.7000

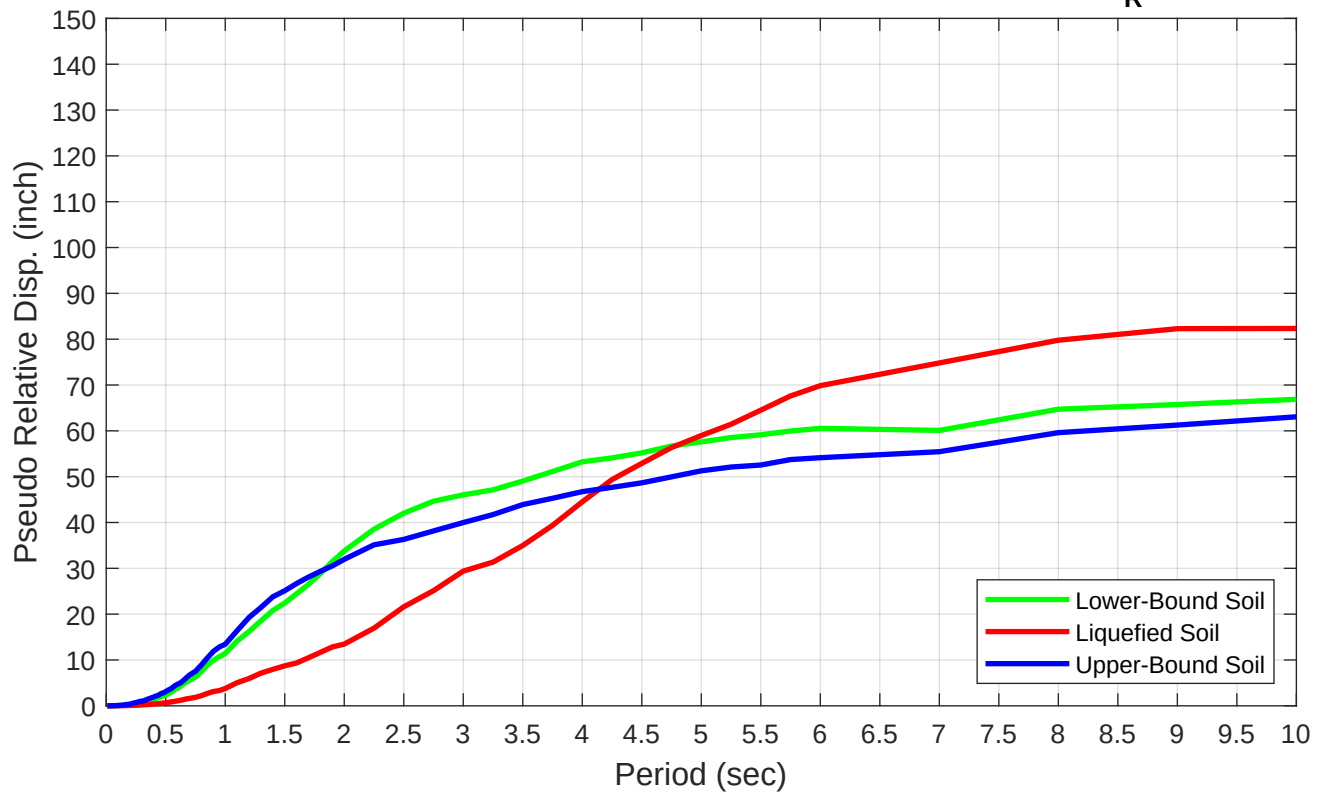
	G/Gmax	Damping (%)
Strain - %	120 to 250 ft	120 to 250 ft
0.0001	1.0000	0.2000
0.0003	1.0000	0.3000
0.001	1.0000	0.6500
0.003	0.9800	1.2000
0.01	0.9000	2.3000
0.03	0.7500	4.2000
0.1	0.5000	8.2000
0.3	0.2800	14.0000
1	0.1200	21.0000
3	0.0660	25.2000
10	0.0370	28.8000

APPENDIX D SITE RESPONSE ANALYSIS RESULTS

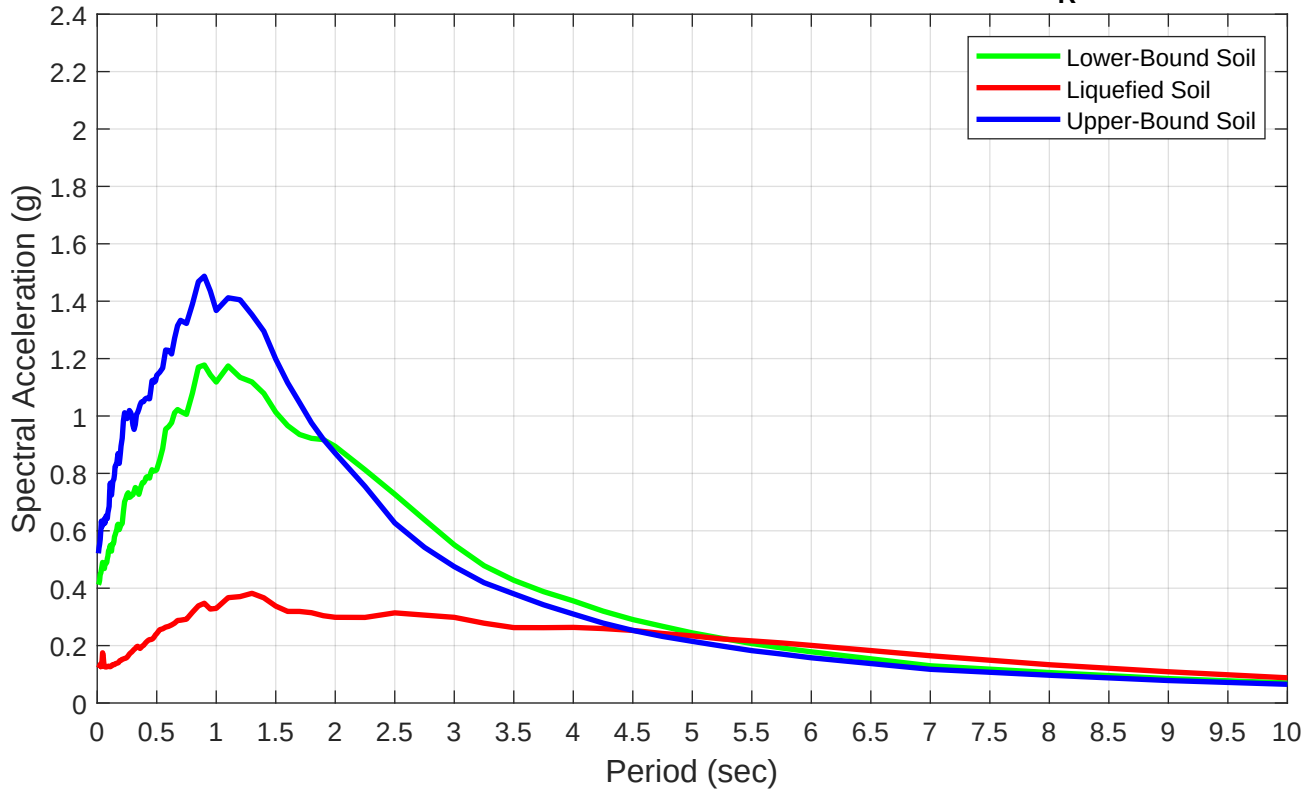
Comparing Spectral Accel. of LB, Liq and UB Soil Profiles - MCE_R Event - Zone I



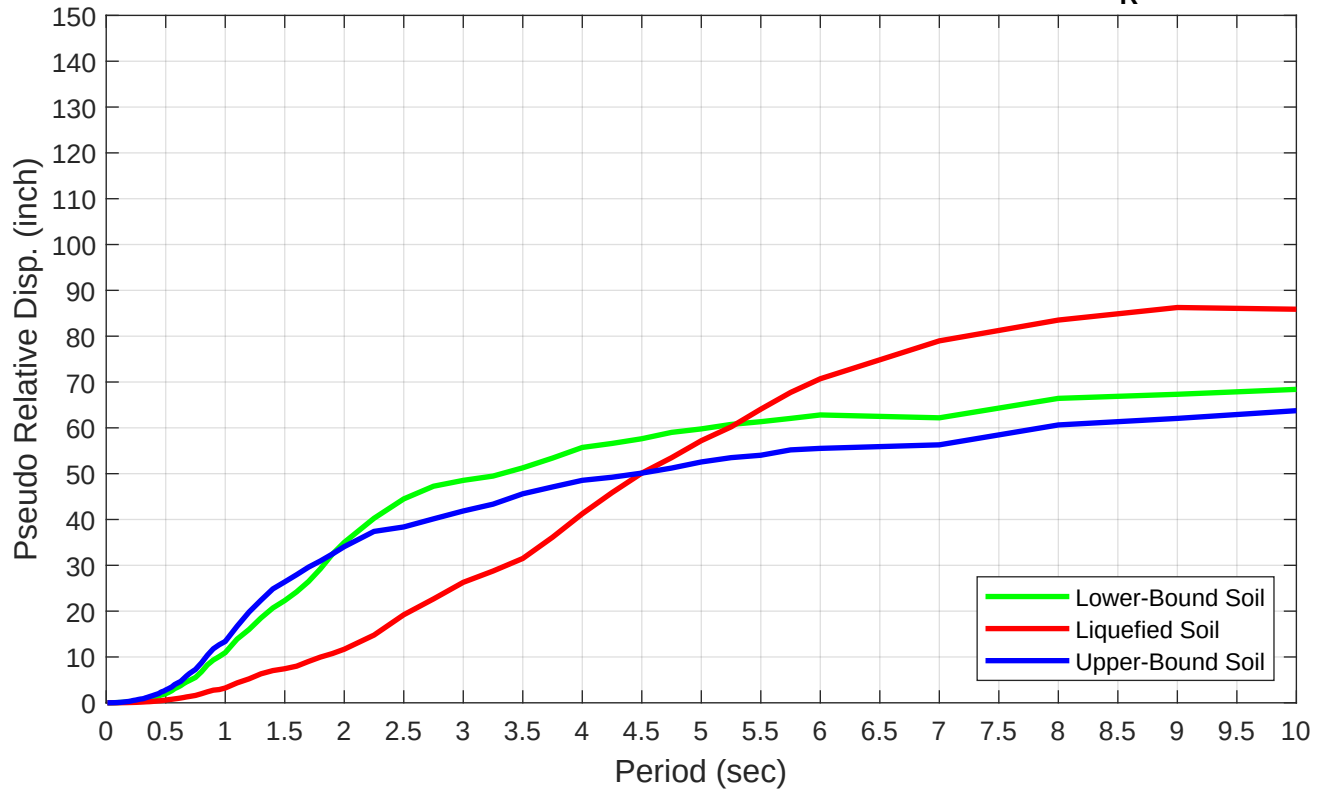
Comparing Pseudo Spectral Disp. of LB, Liq and UB Soil Profiles - MCE_R Event - Zone I



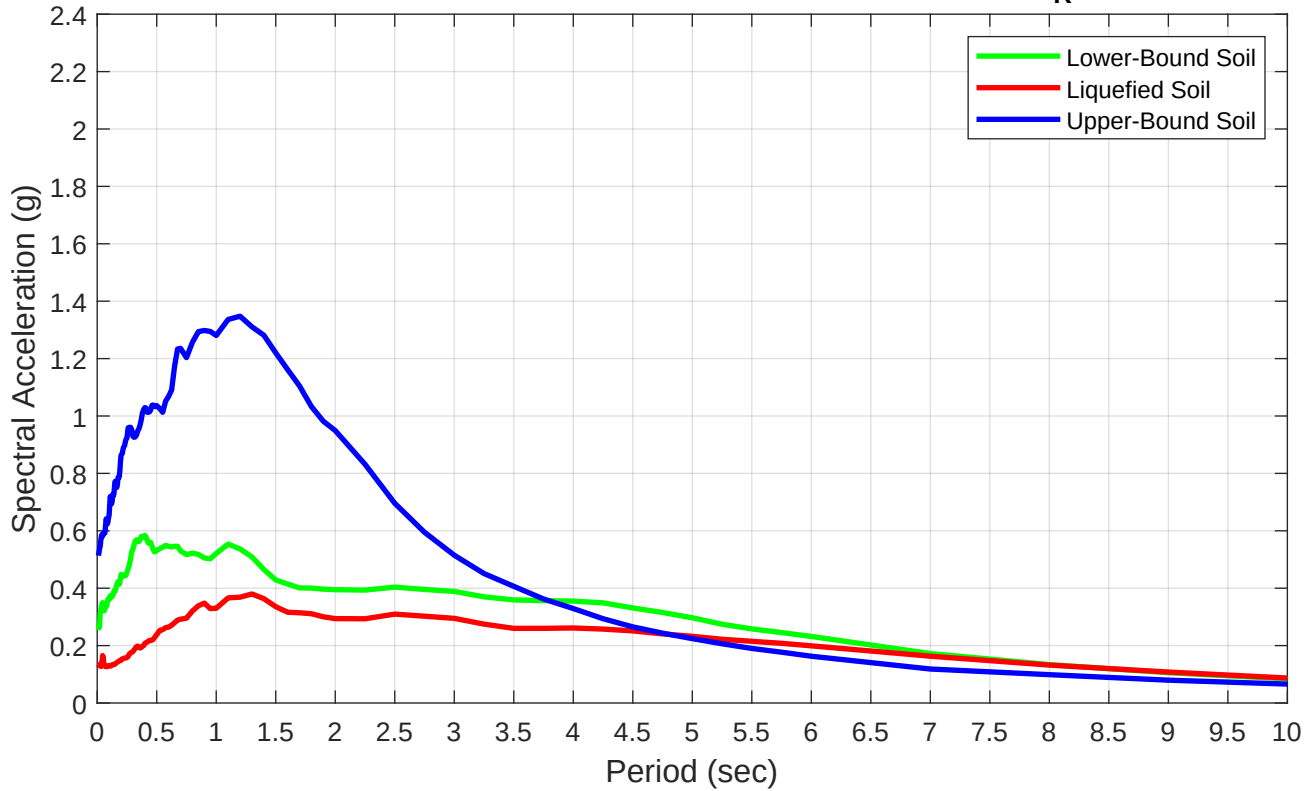
Comparing Spectral Accel. of LB, Liq and UB Soil Profiles - MCE_R Event - Zone II



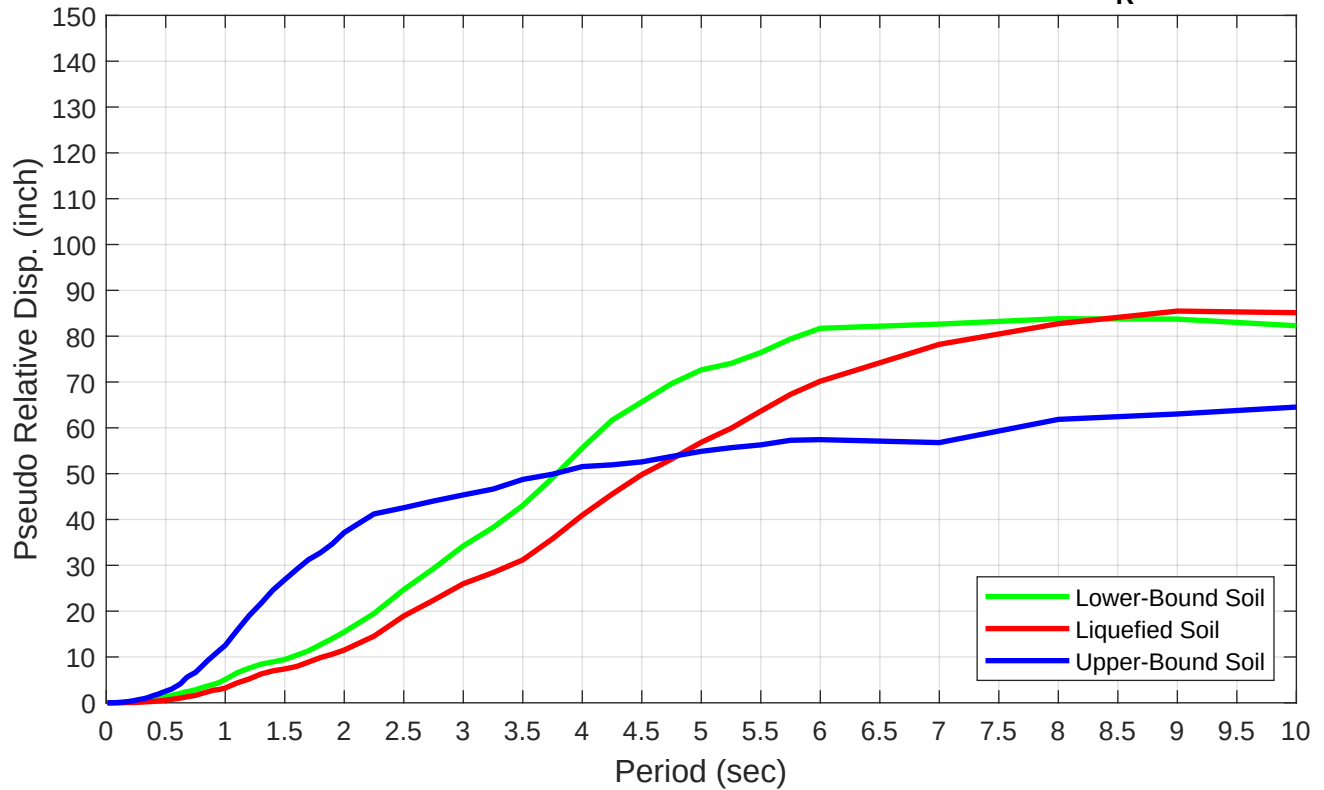
Comparing Pseudo Spectral Disp. of LB, Liq and UB Soil Profiles - MCE_R Event - Zone II



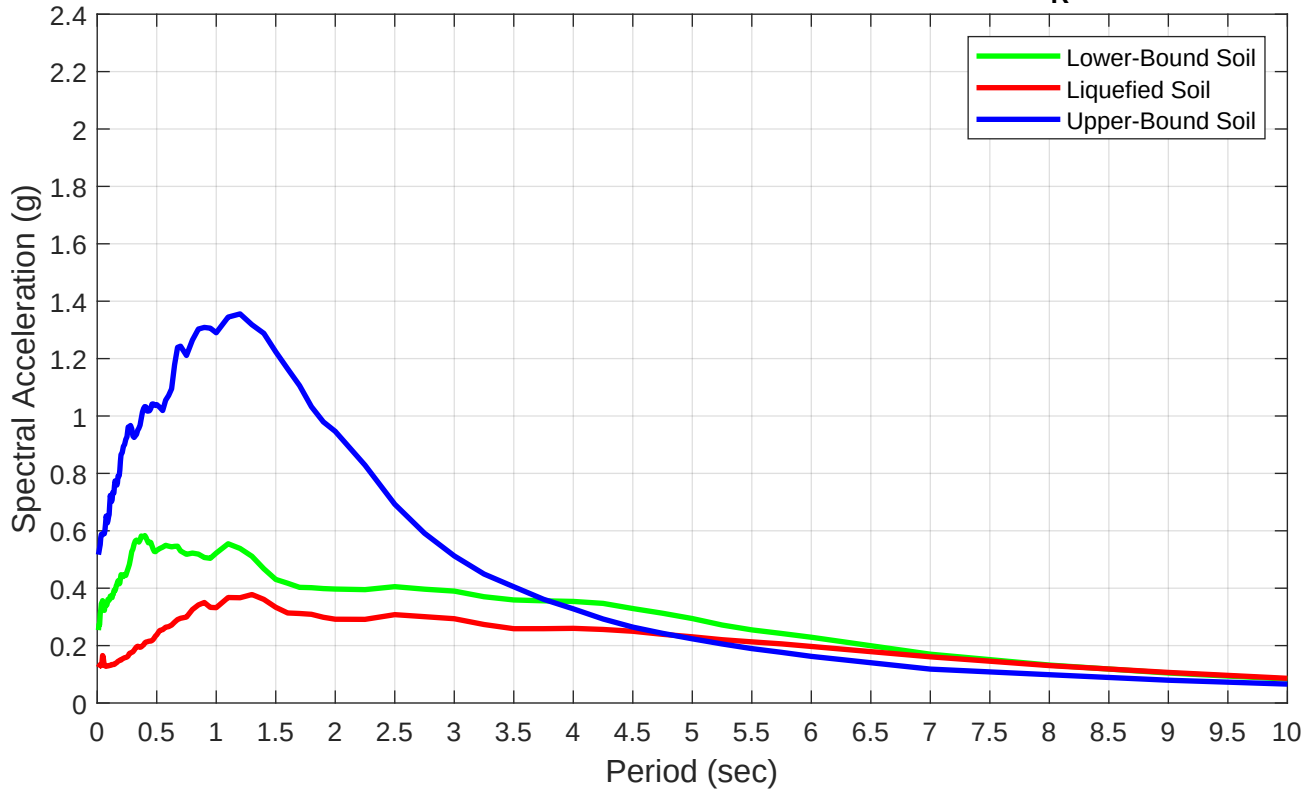
Comparing Spectral Accel. of LB, Liq and UB Soil Profiles - MCE_R Event - Zone III



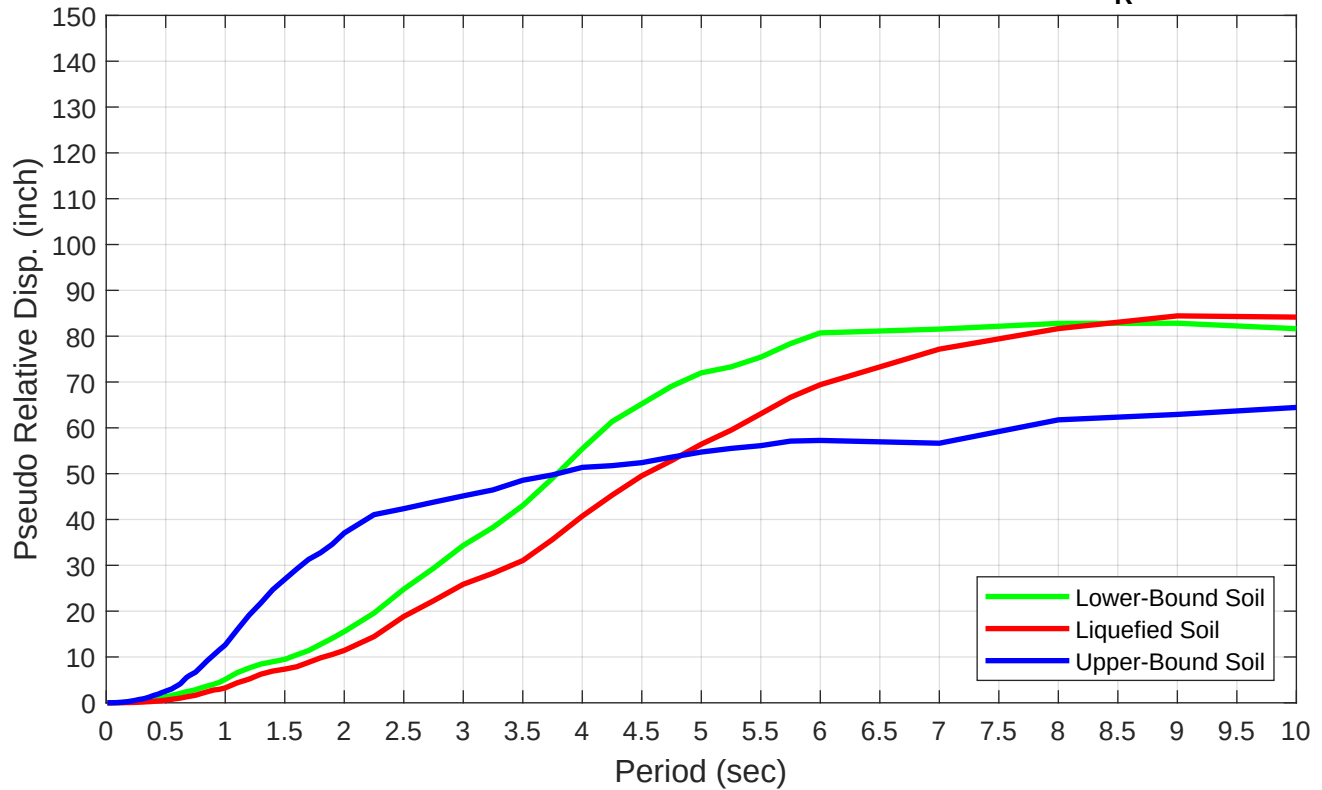
Comparing Pseudo Spectral Disp. of LB, Liq and UB Soil Profiles - MCE_R Event - Zone III



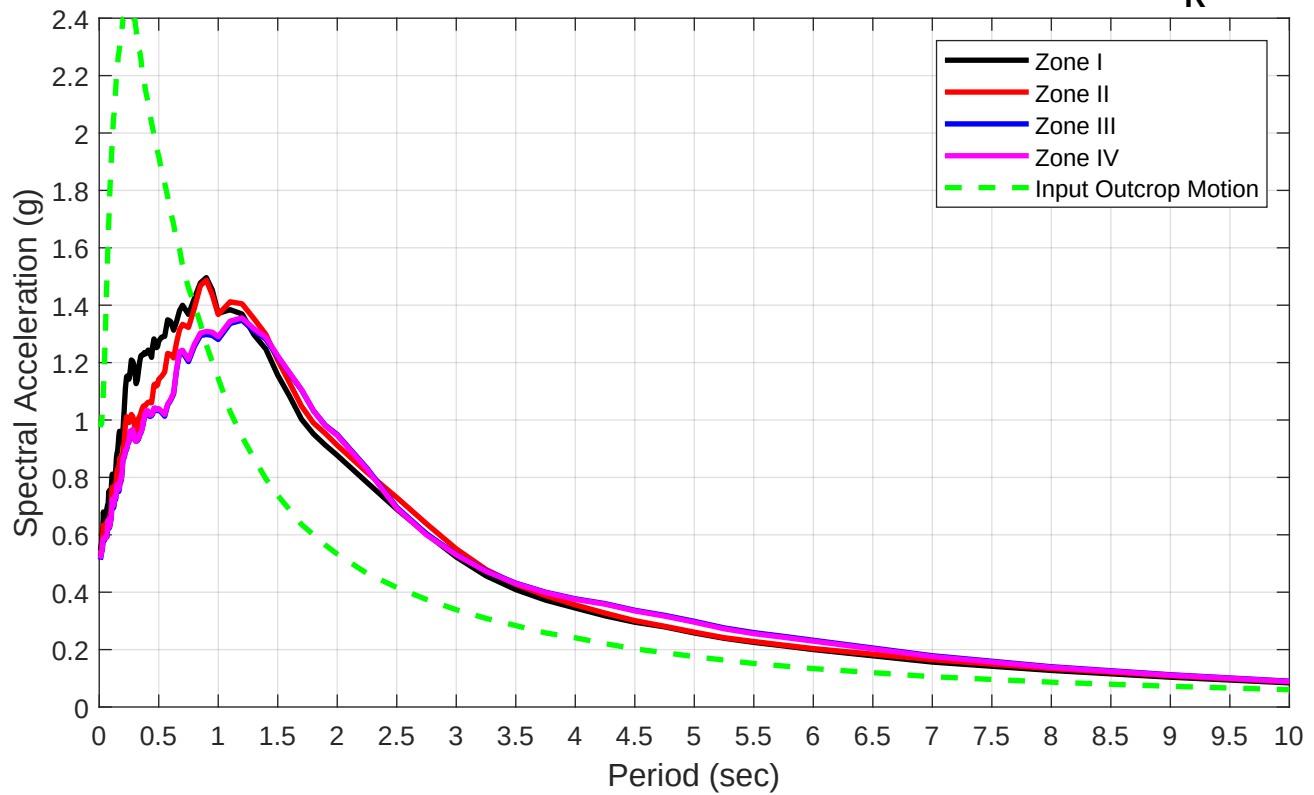
Comparing Spectral Accel. of LB, Liq and UB Soil Profiles - MCE_R Event - Zone IV



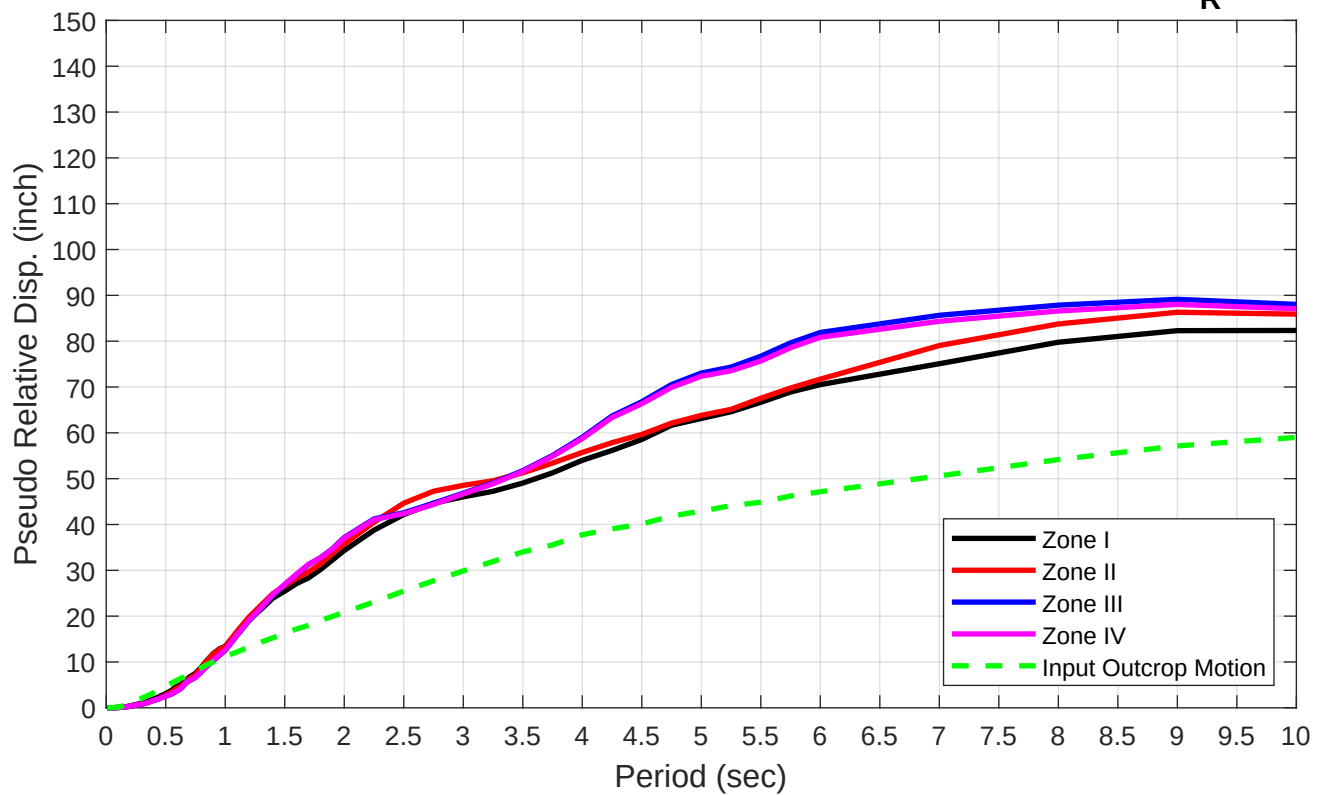
Comparing Pseudo Spectral Disp. of LB, Liq and UB Soil Profiles - MCE_R Event - Zone IV



Comparing Spectral Accel. of Zones I, II, III, and IV - MCE_R



Comparing Pseudo Spectral Disp. of Zones I, II, III, and IV - MCE_R Event



**APPENDIX E SPECTRUM-MATCHED GROUND MOTION TIME HISTORIES FOR
REFERENCE BEDROCK, FIRM (IMPROVED) GROUND AND UNIMPROVED
GROUND FOR DE EVENT**



The seven (7) sets of three-component ground motion time histories listed in Table E1 have been modified using a time-domain approach to match the Design Earthquake (DE) response spectra for both firm (improved) and unimproved ground conditions. Each set includes three (3) components (FN, FP, and Vertical), resulting in a total of 21 time histories for each ground condition. For each time history, the following is plotted:

- ❖ Initial acceleration, velocity and displacement time histories scaled to PGA,
- ❖ Modified (spectral-matched) acceleration, velocity and displacement time histories, and
- ❖ Comparison of the target acceleration and relative displacement spectra with the spectra of the initial and the modified time histories.

The plots for firm (improved) ground are shown in Figure E1 through Figure E21 for the DE. The plots for unimproved ground are shown in Figure E22 through Figure E42.

Table E1. SELECTED STARTUP MOTIONS FOR THE DE

Set	PEER RSN *	Earthquake	Mw	Pulse Motion	Station	Distance, R_{rup} (km)
1	1787	1999 Hector Mine	7.1	No	Hector	11.7
2	767	1989 Loma Prieta	6.9	Yes	Gilroy Array 0#3	12.8
3	2114	2002 Denali, Alaska	7.9	Yes	TAPS Pump Station #10	2.7
4	1612	1999 Duzce, Turkey	7.1	No	Lamont 1059	4.2
5	6906	2010 Darfield, New Zealand	7.0	Yes	GDLC	1.2
6	6	1940 Imperial Valley	6.9	No	El Centro	6.1
7	1108	1995 Kobe, Japan	6.9	No	Kobe University	0.9

* PEER ground motion database (<https://ngawest2.berkeley.edu/>).

PART I:
SPECTRUM-MATCHED GROUND MOTIONS FOR DE FOR FIRM (IMPROVED)
GROUND CONDITION

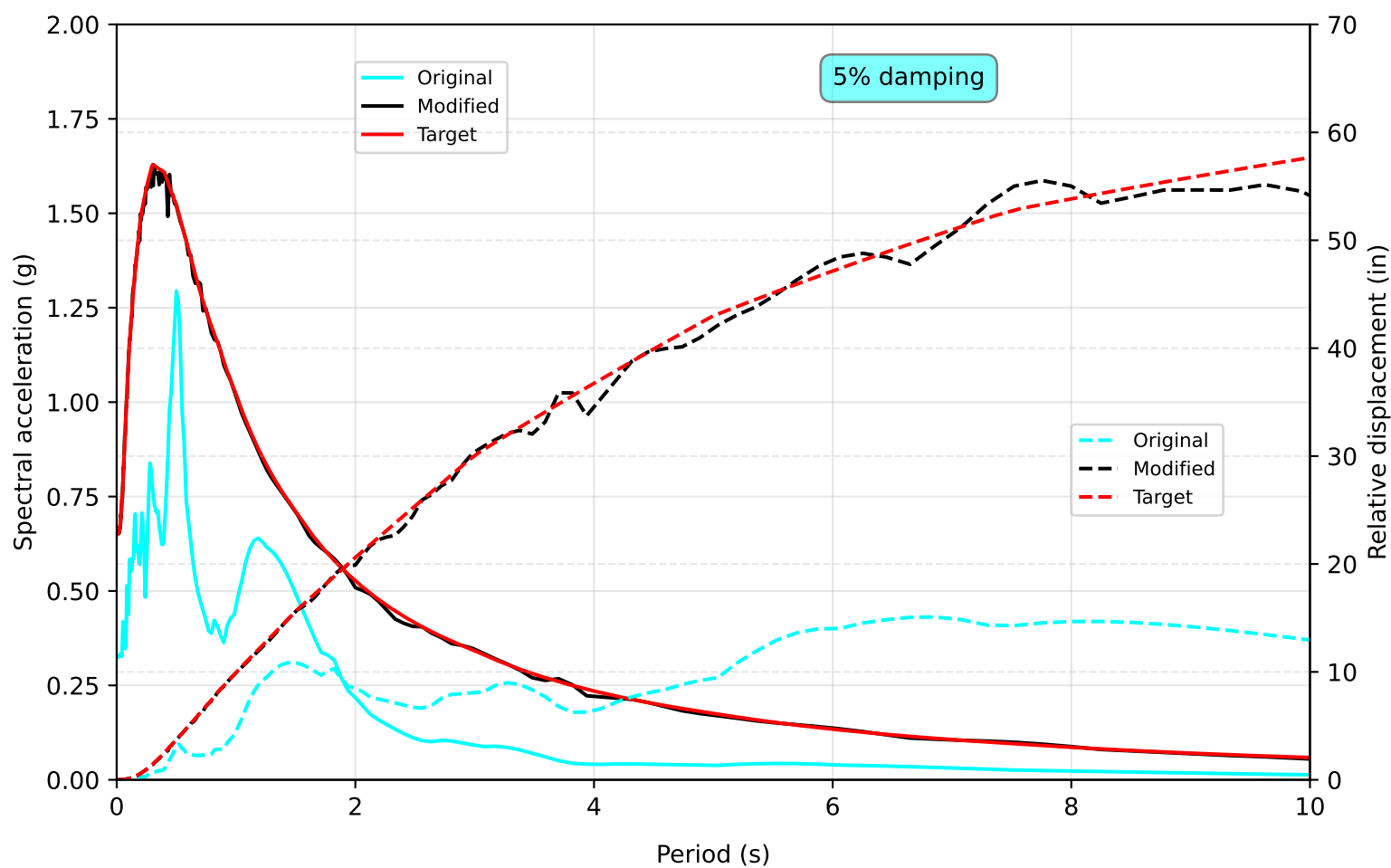
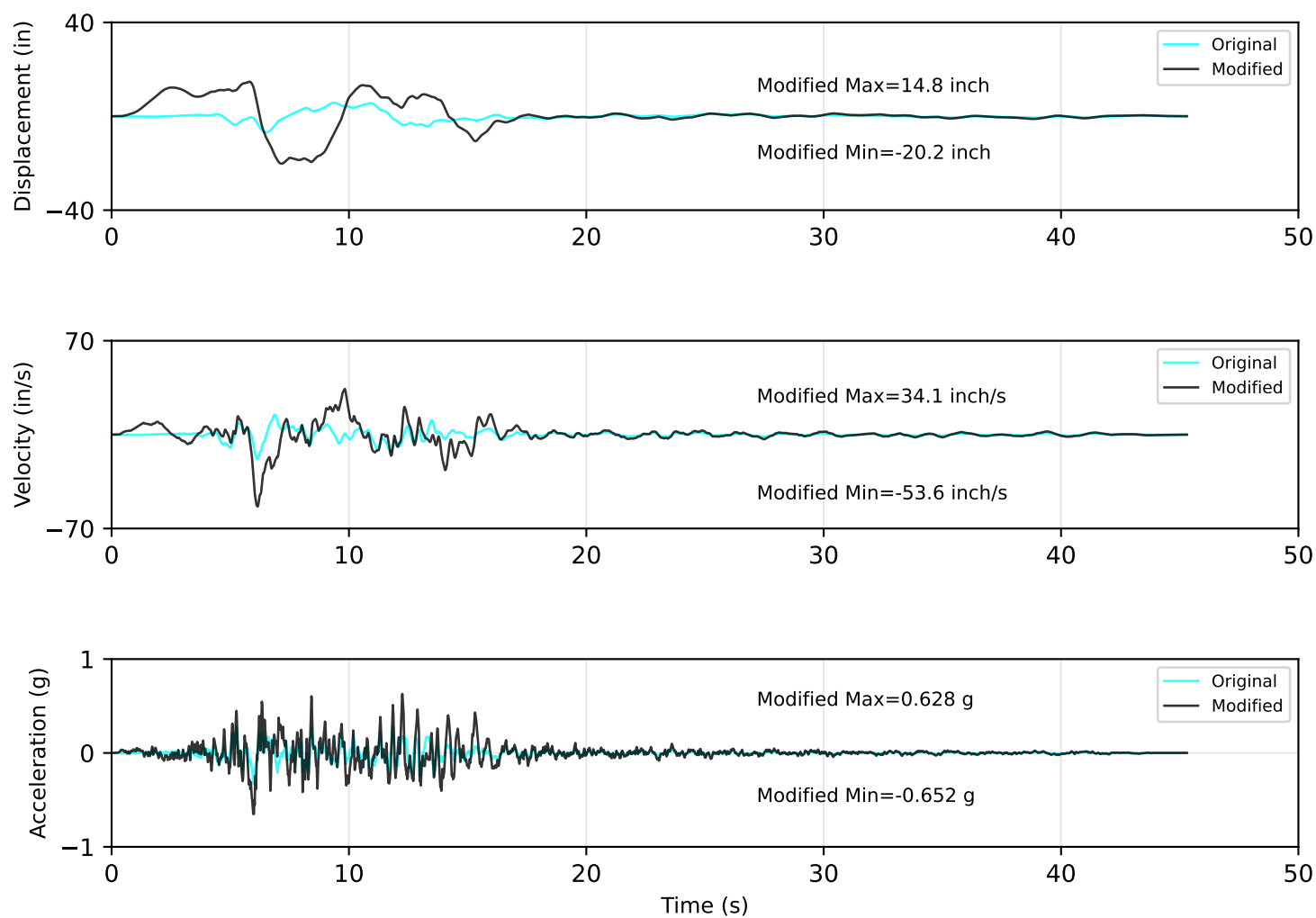


Figure E1. Firm (Improved) Ground ASCE 7-22 DE Spectrum-matched Ground Motion - Set-1-Fault Normal

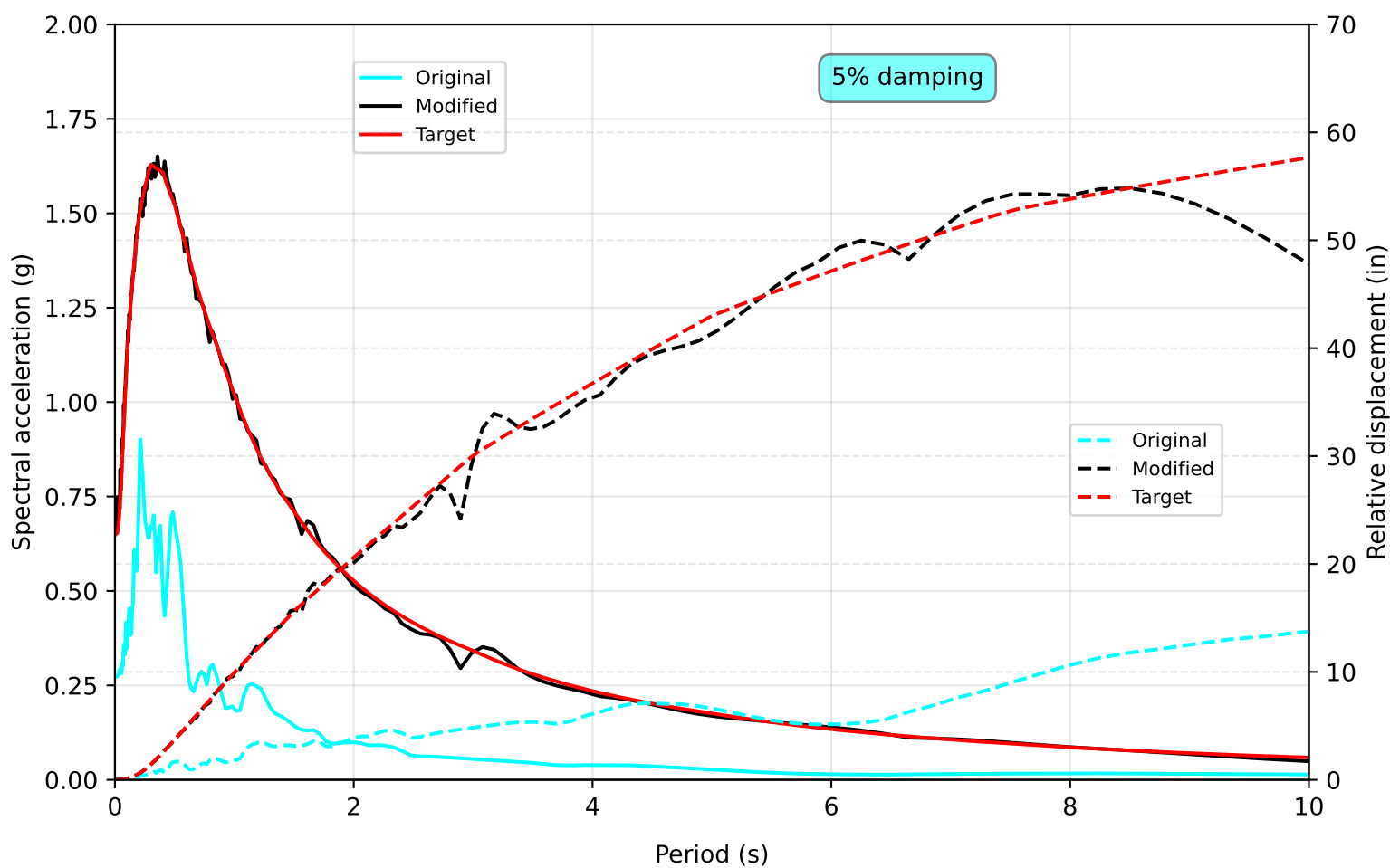
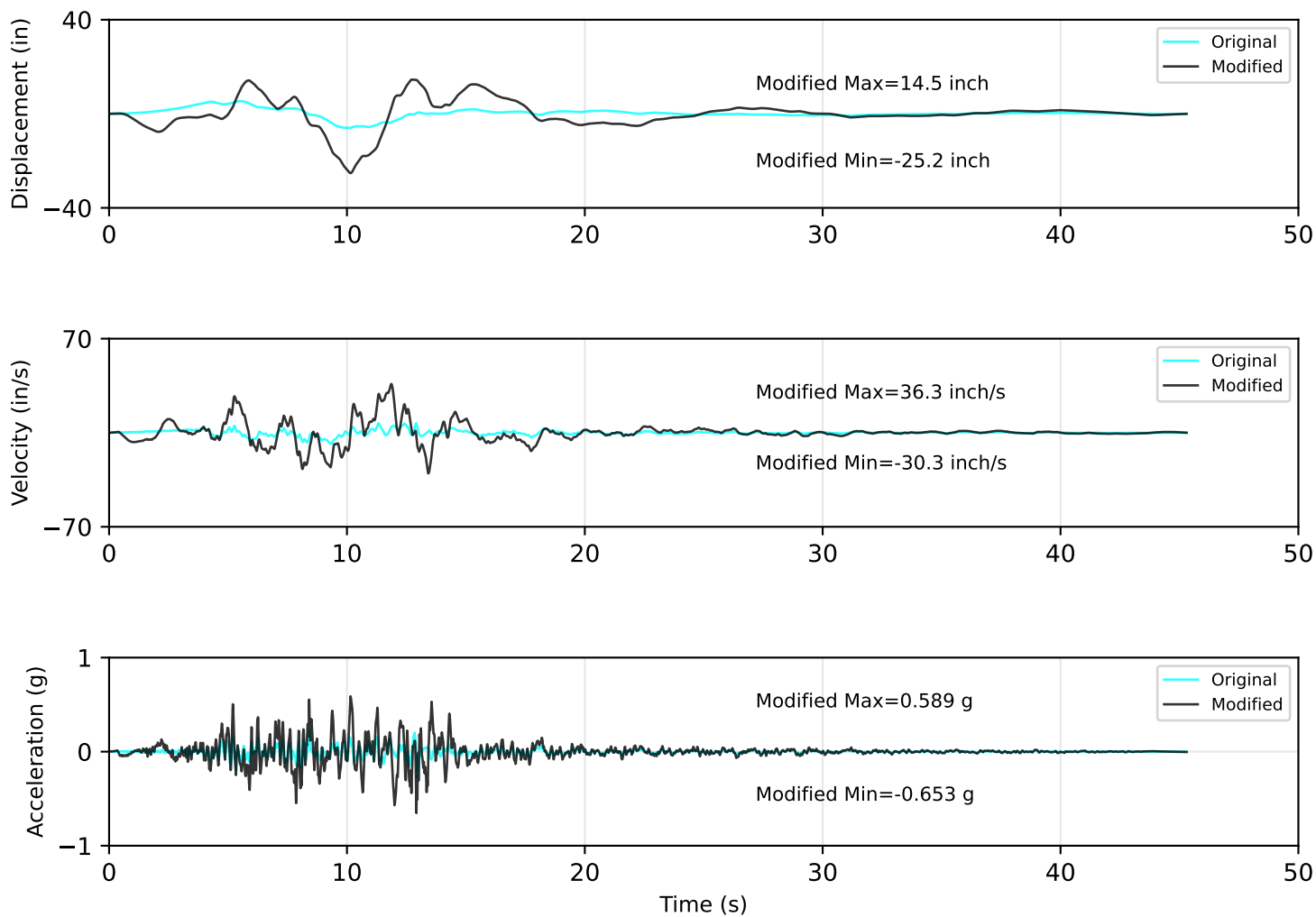


Figure E2. Firm (Improved) Ground ASCE 7-22 DE Spectrum-matched Ground Motion - Set-1-Fault Parallel

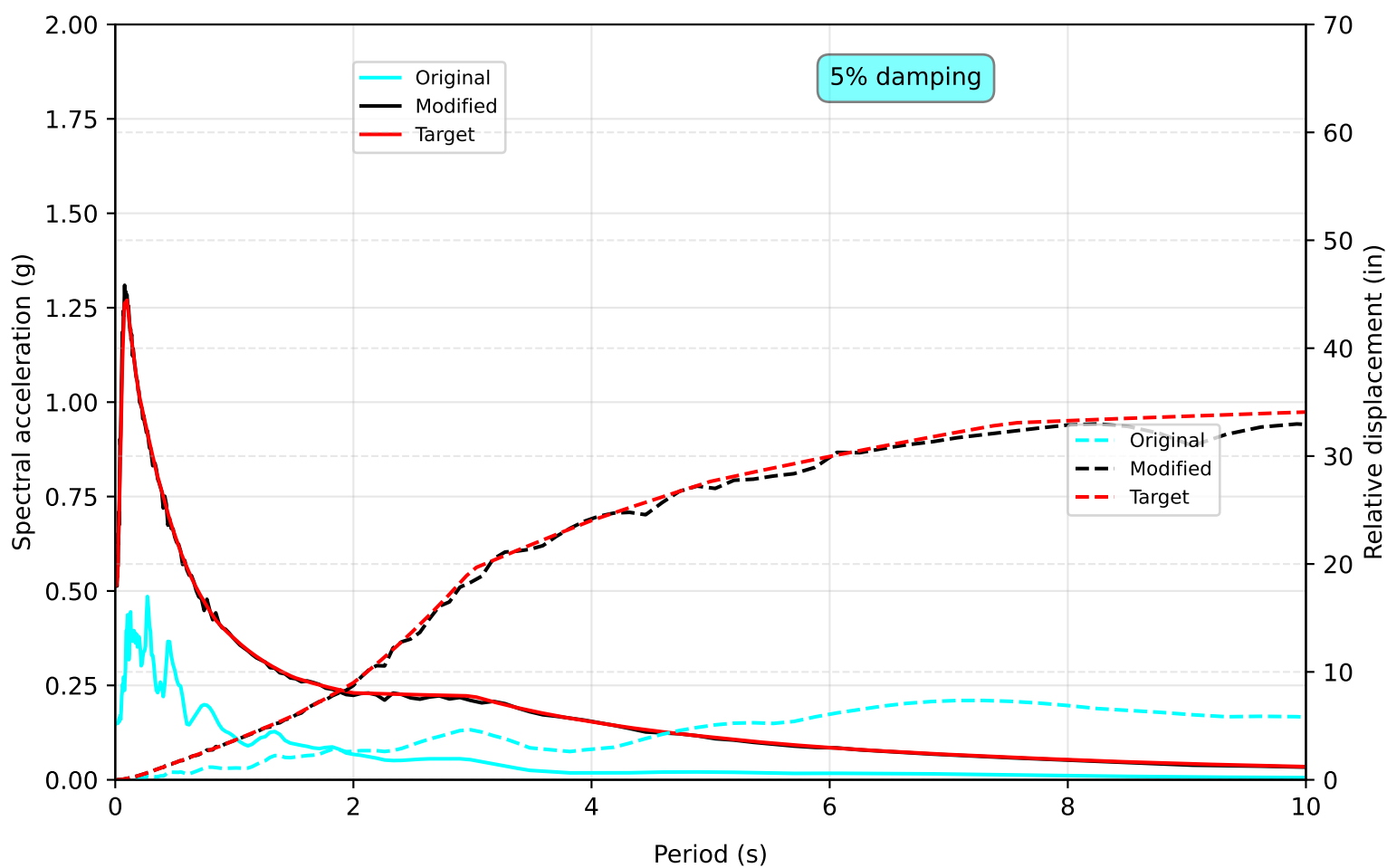
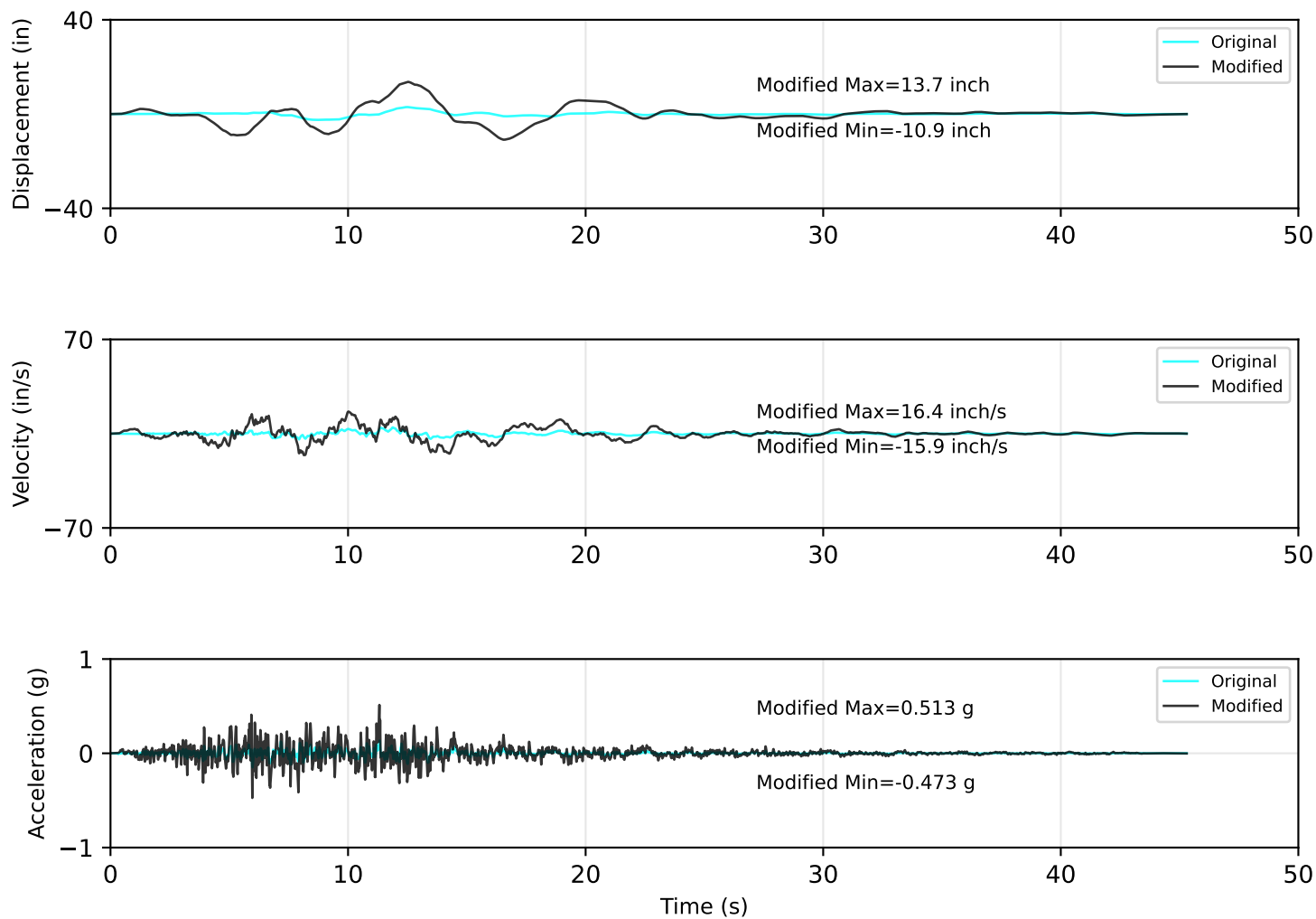


Figure E3. Firm (Improved) Ground ASCE 7-22 DE Spectrum-matched Ground Motion - Set-1 Vertical

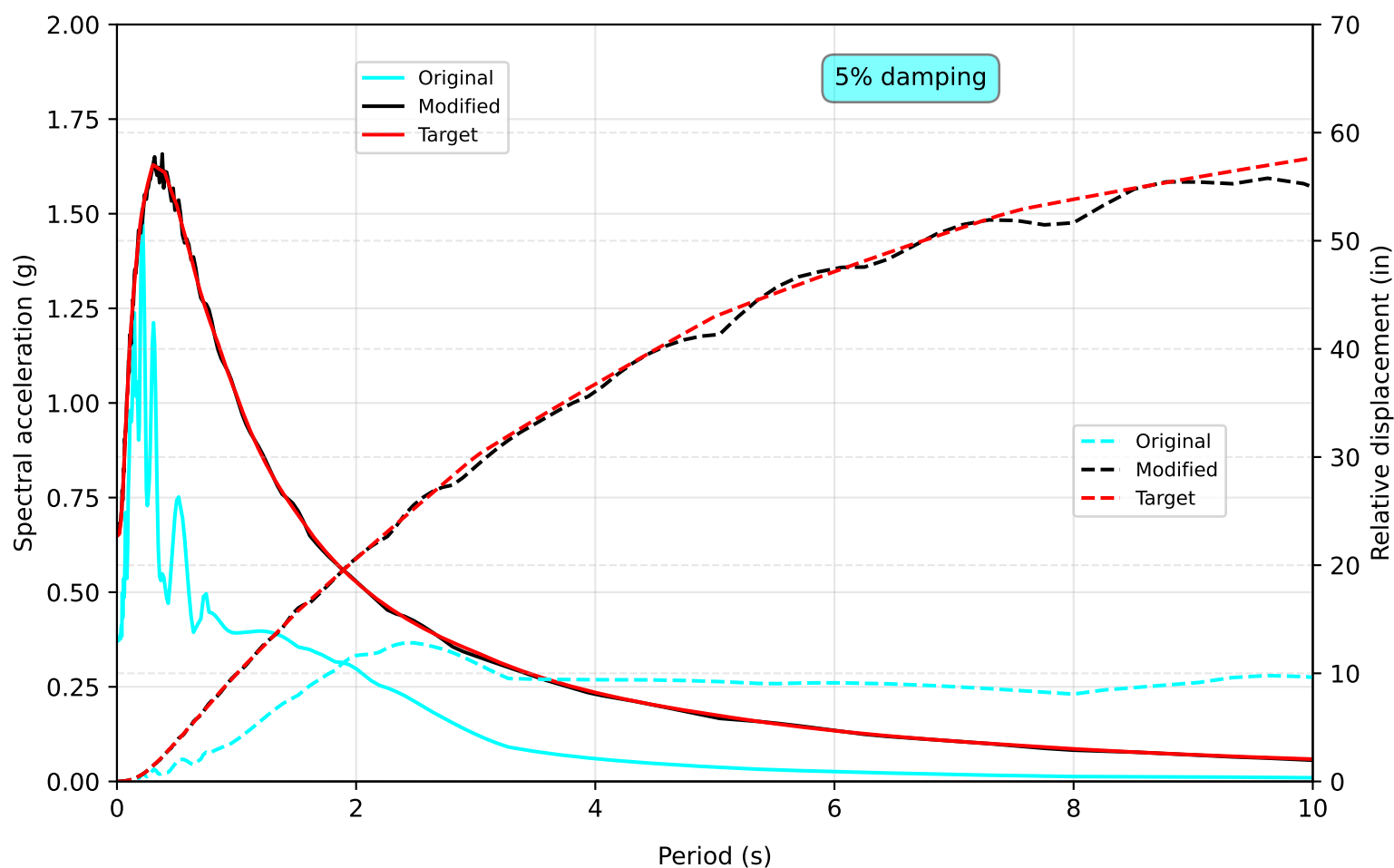
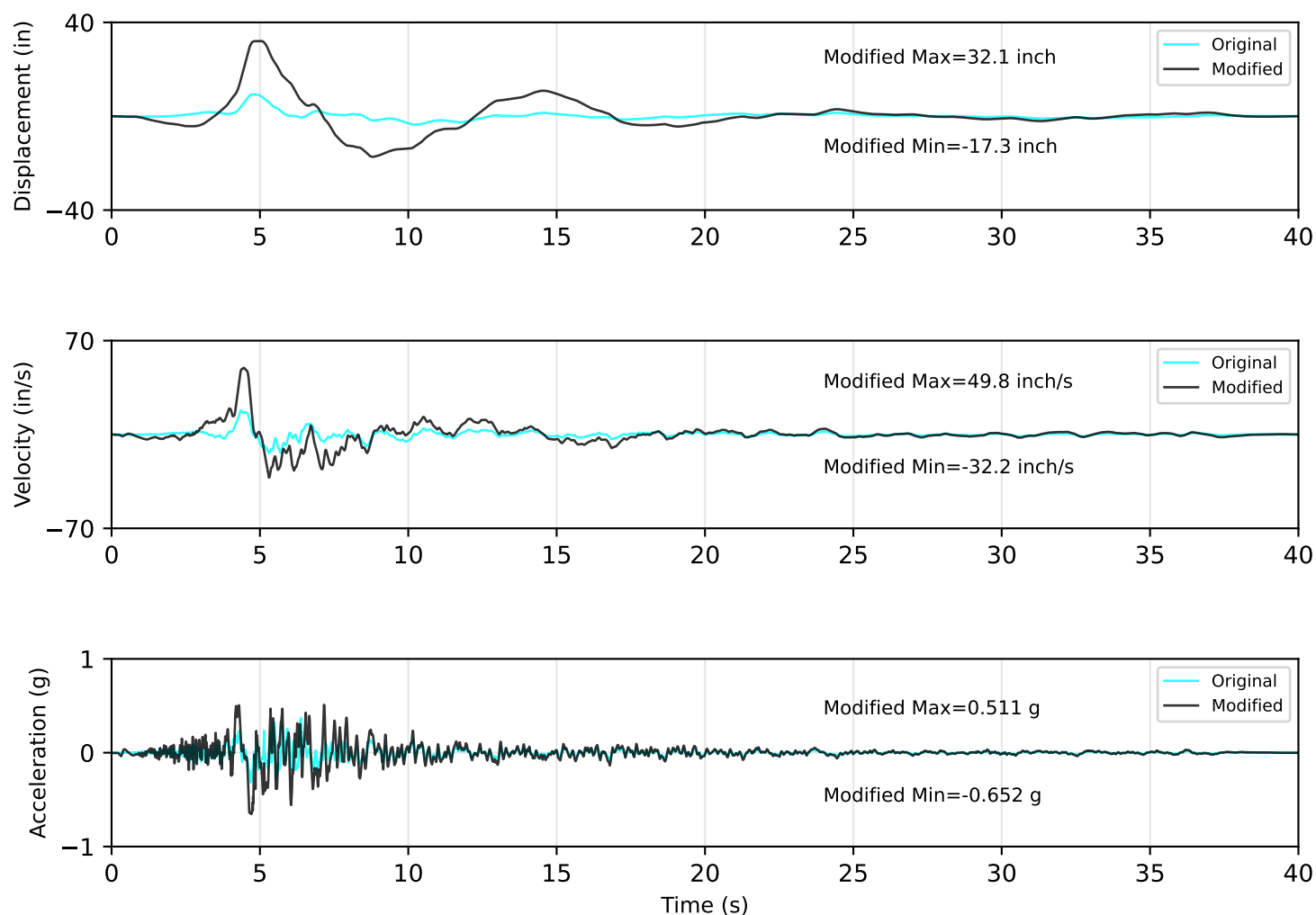


Figure E4. Firm (Improved) Ground ASCE 7-22 DE Spectrum-matched Ground Motion - Set-2-Fault Normal

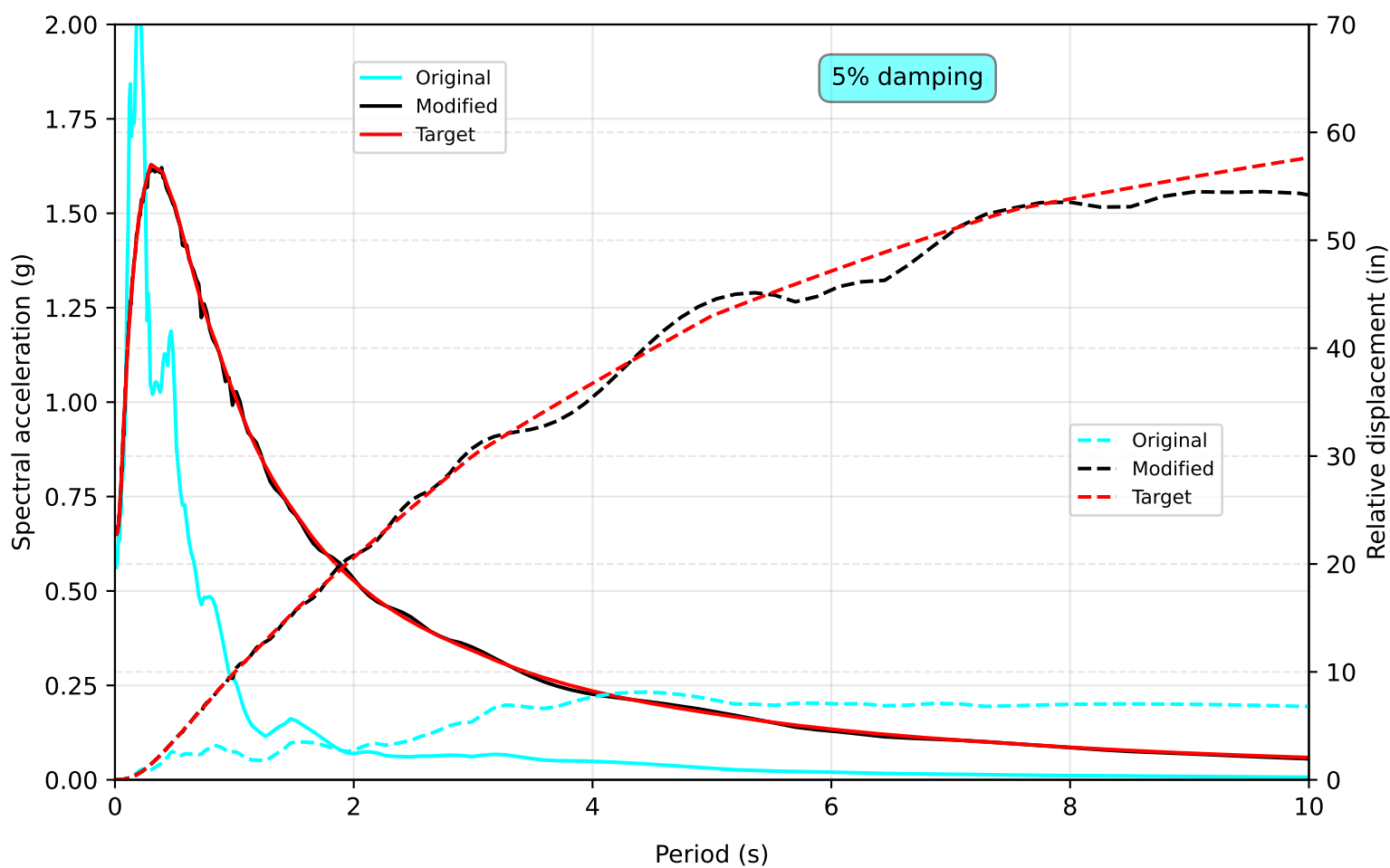
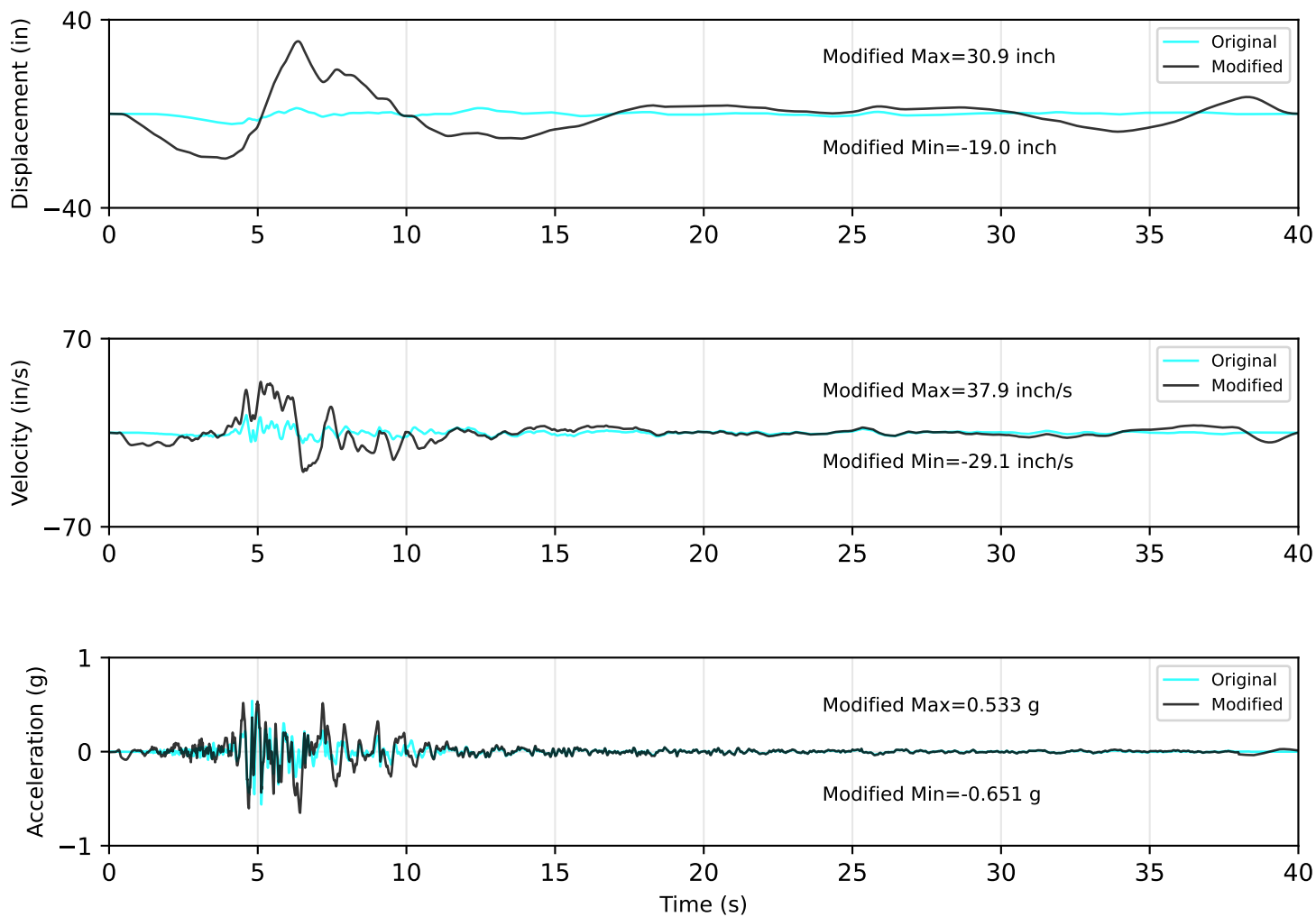


Figure E5. Firm (Improved) Ground ASCE 7-22 DE Spectrum-matched Ground Motion - Set-2-Fault Parallel

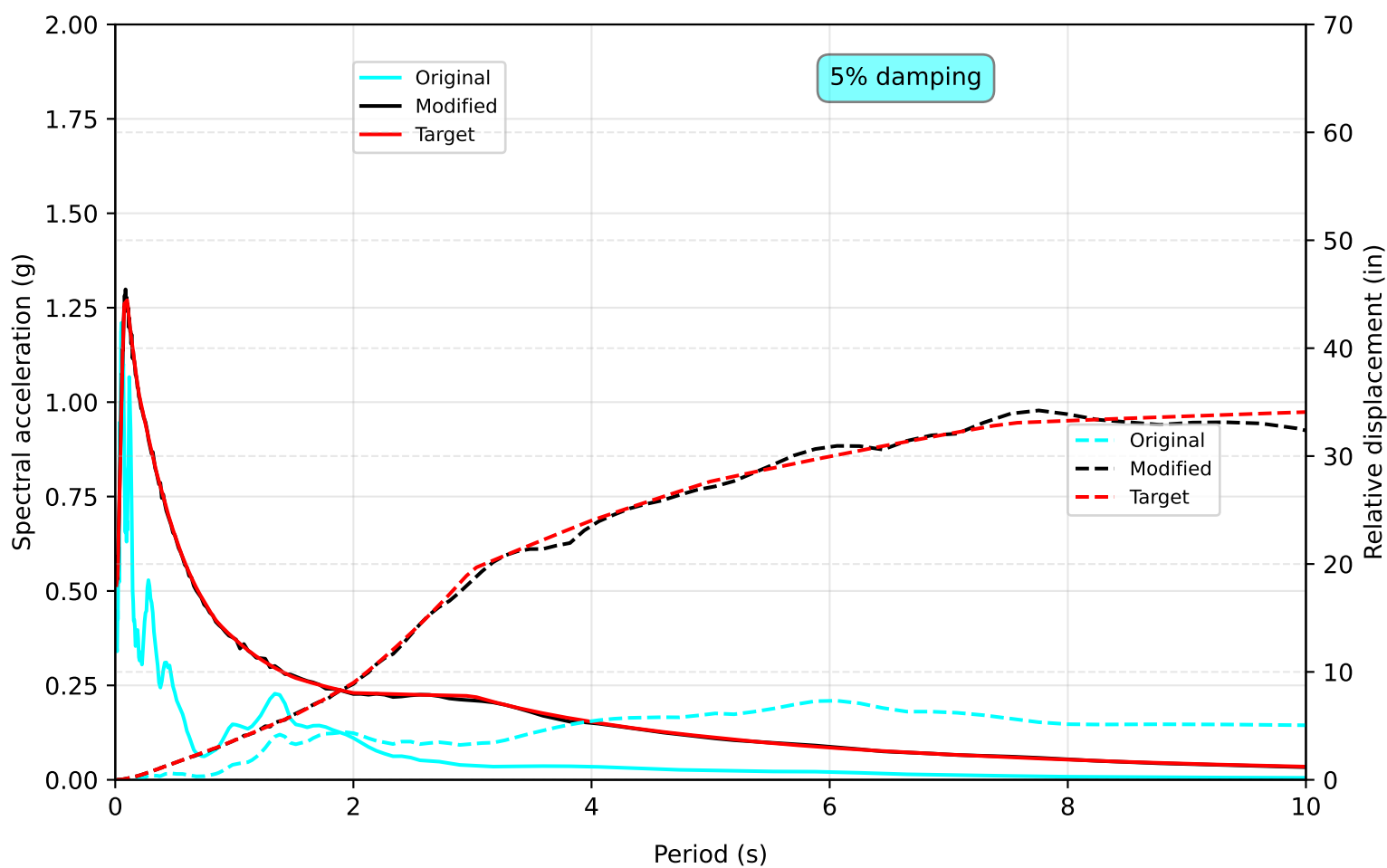
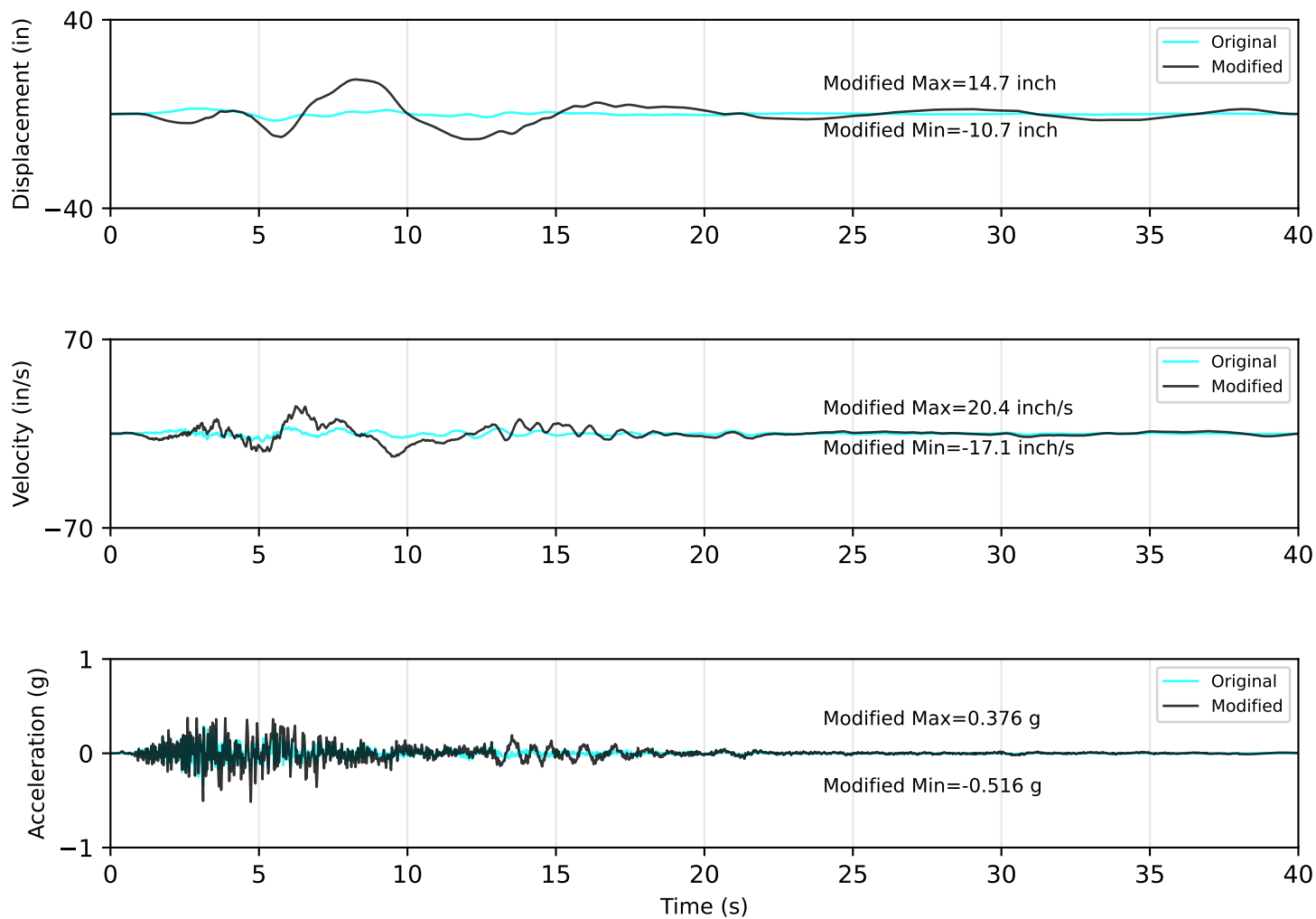


Figure E6. Firm (Improved) Ground ASCE 7-22 DE Spectrum-matched Ground Motion - Set-2 Vertical

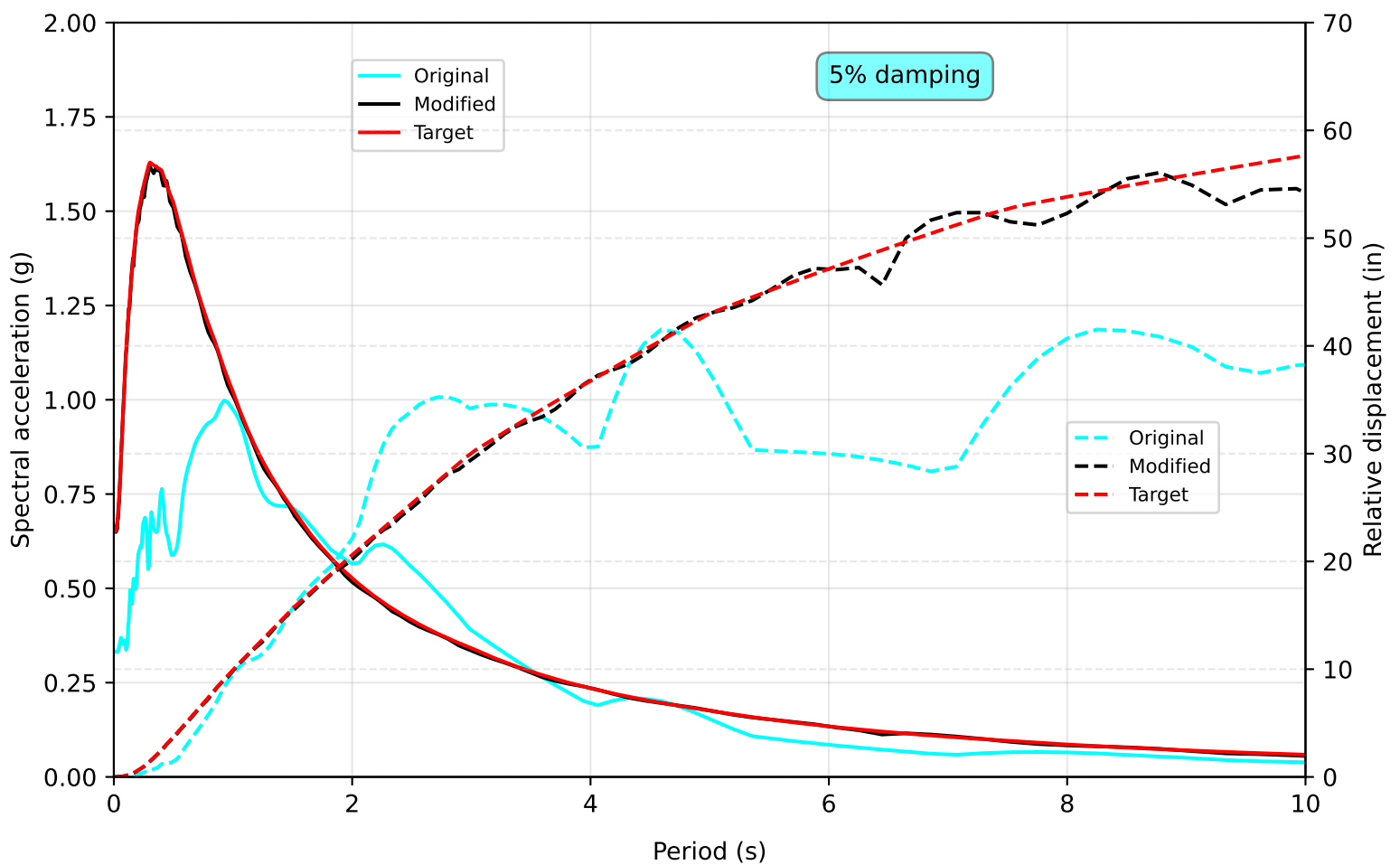
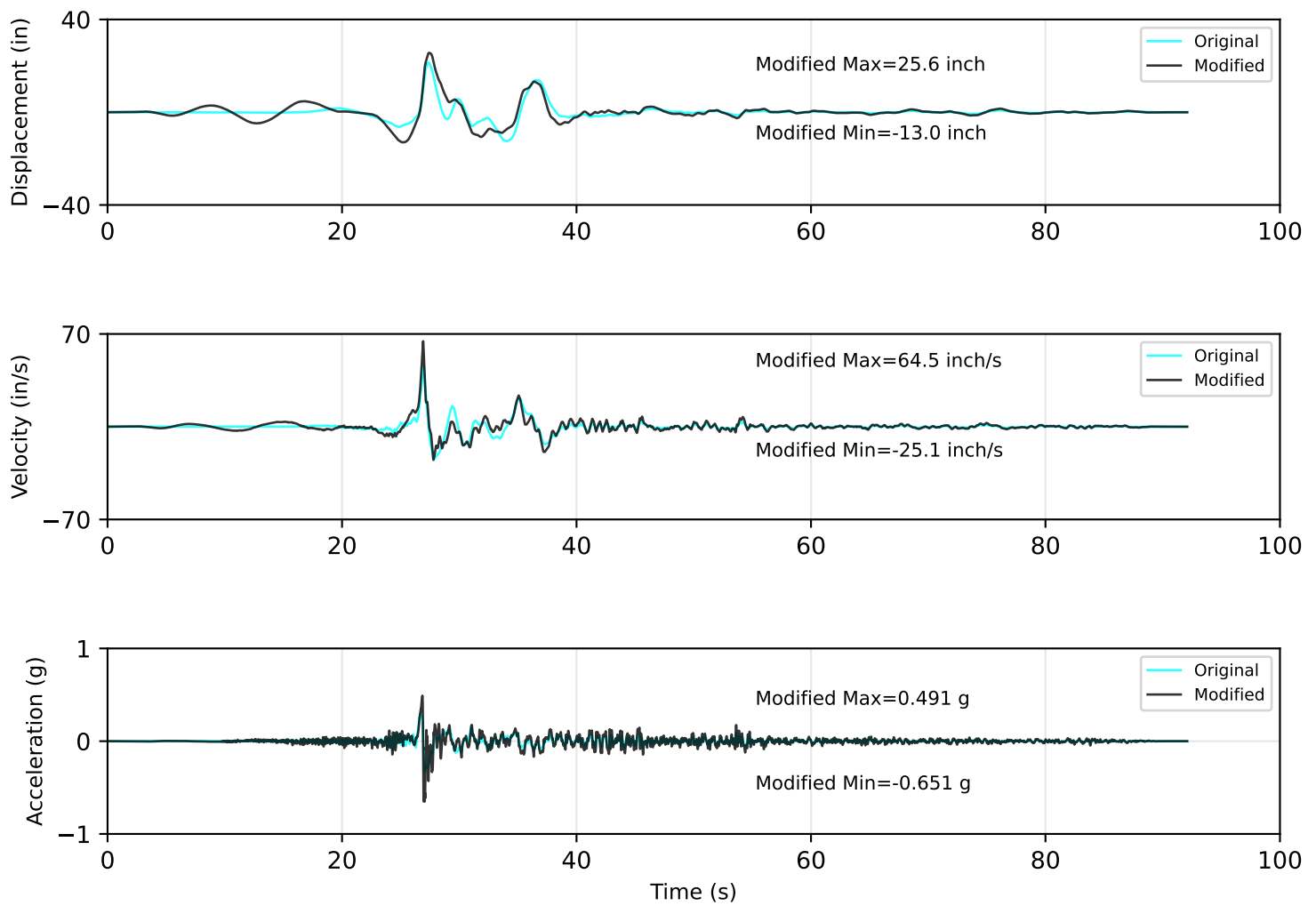


Figure E7. Firm (Improved) Ground ASCE 7-22 DE Spectrum-matched Ground Motion - Set-3-Fault Normal

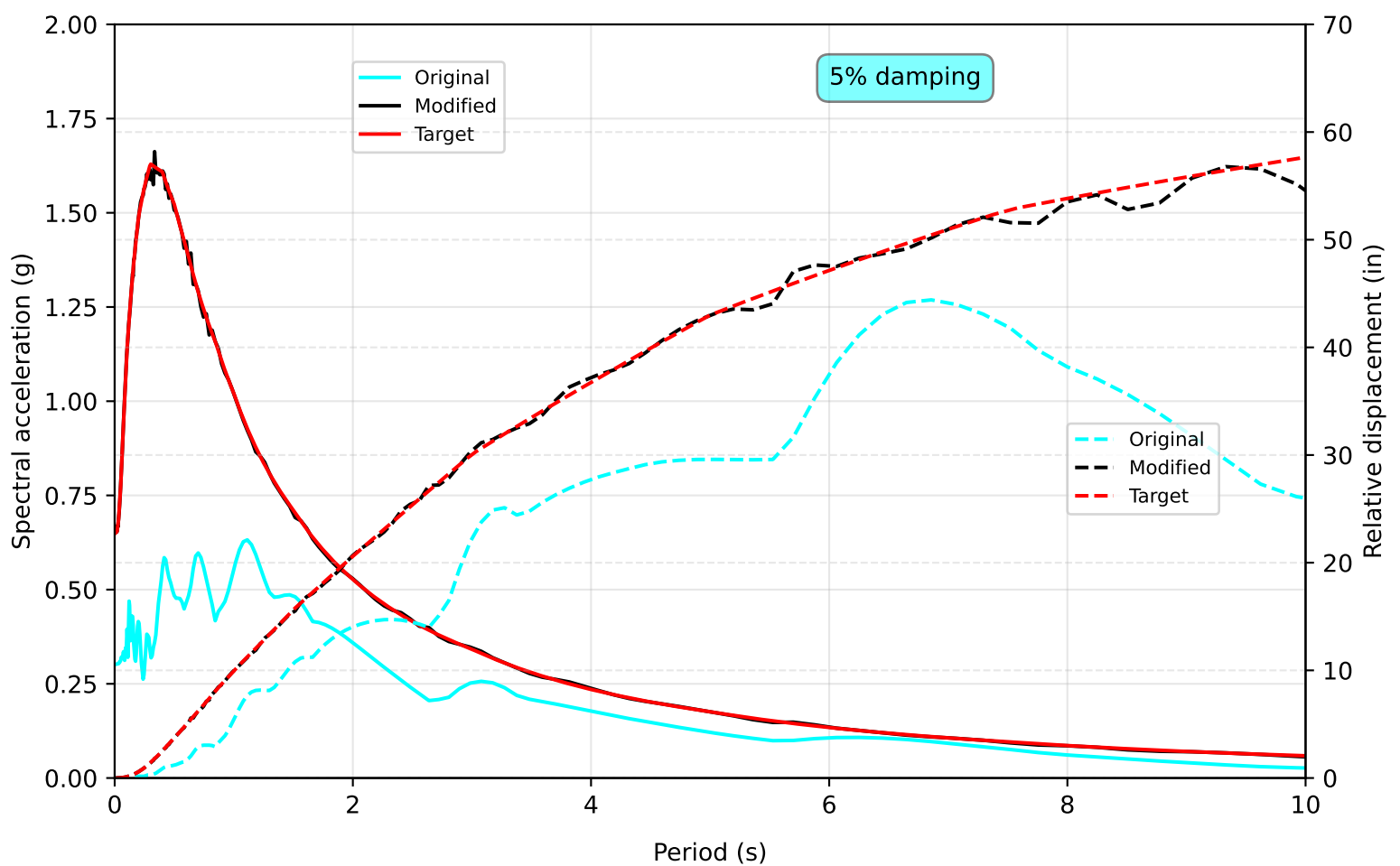
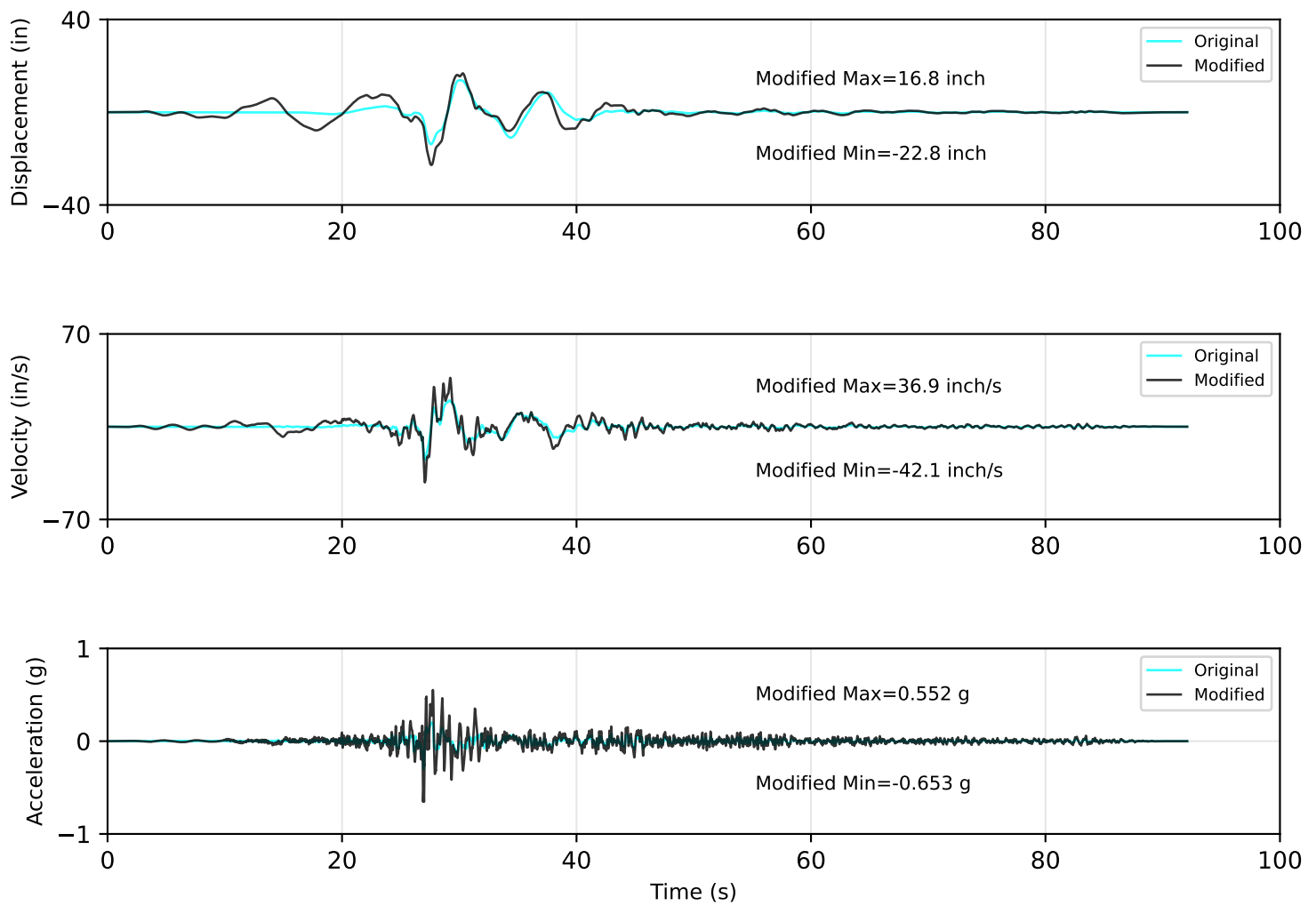


Figure E8. Firm (Improved) Ground ASCE 7-22 DE Spectrum-matched Ground Motion - Set-3-Fault Parallel

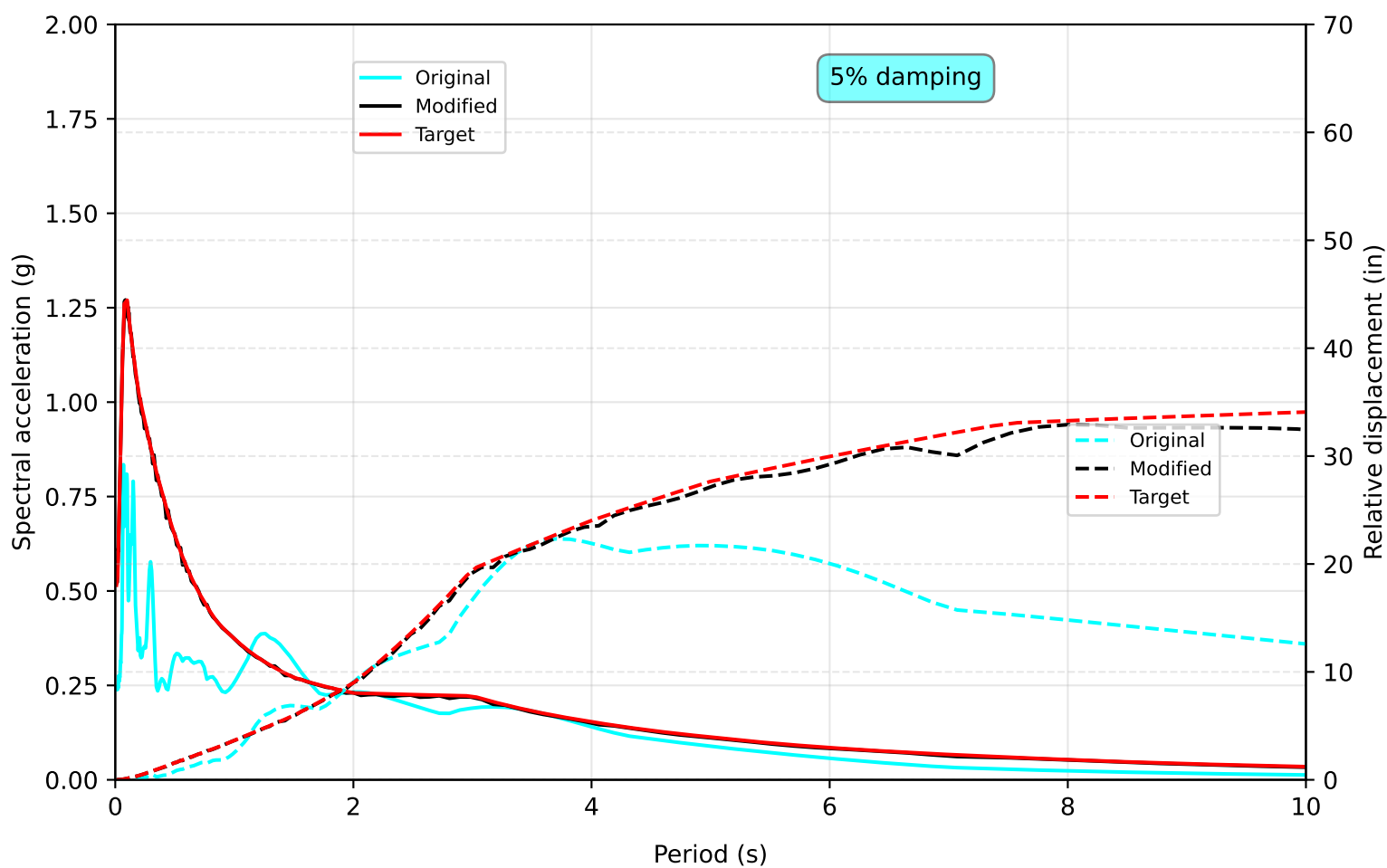
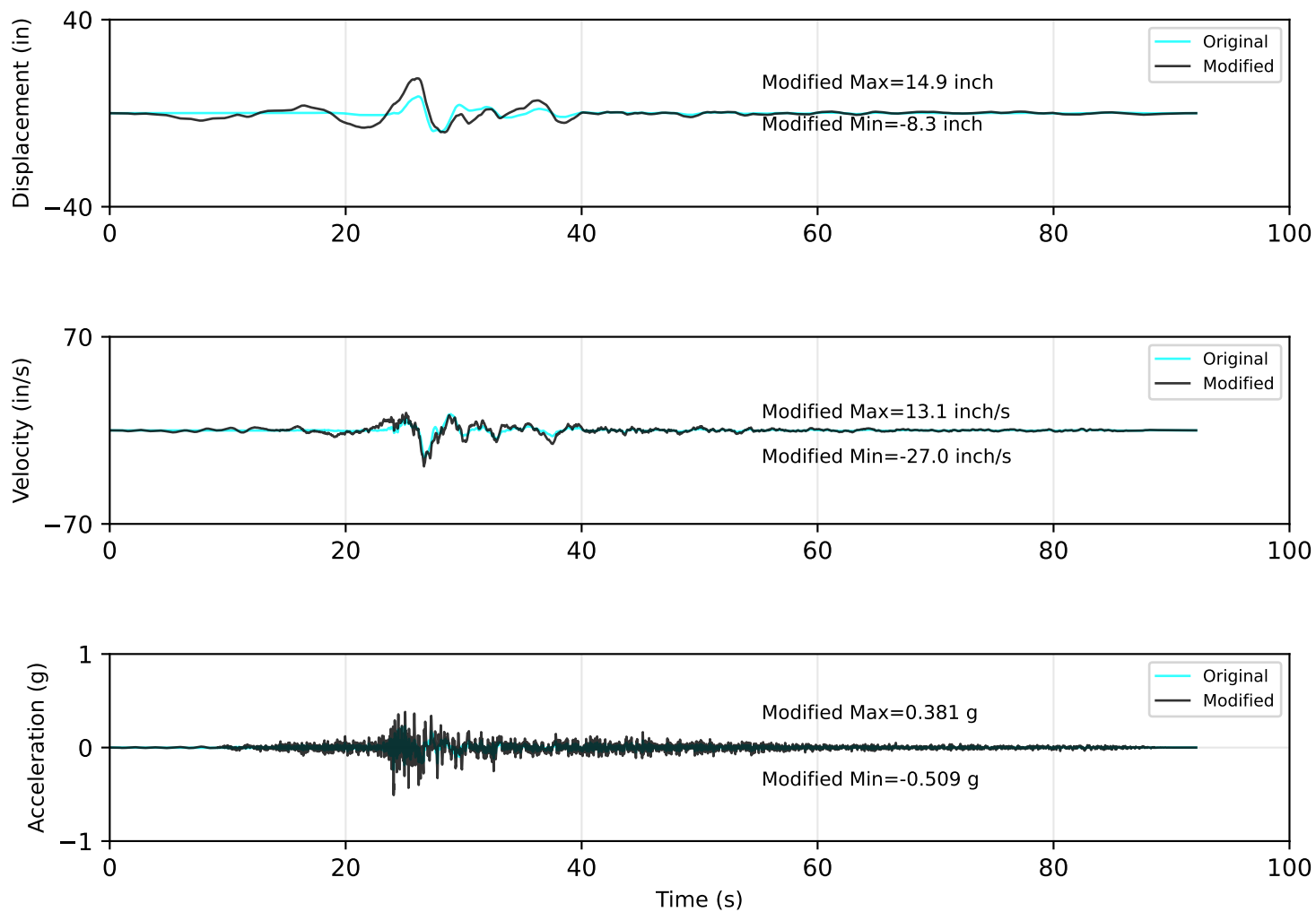


Figure E9. Firm (Improved) Ground ASCE 7-22 DE Spectrum-matched Ground Motion - Set-3 Vertical

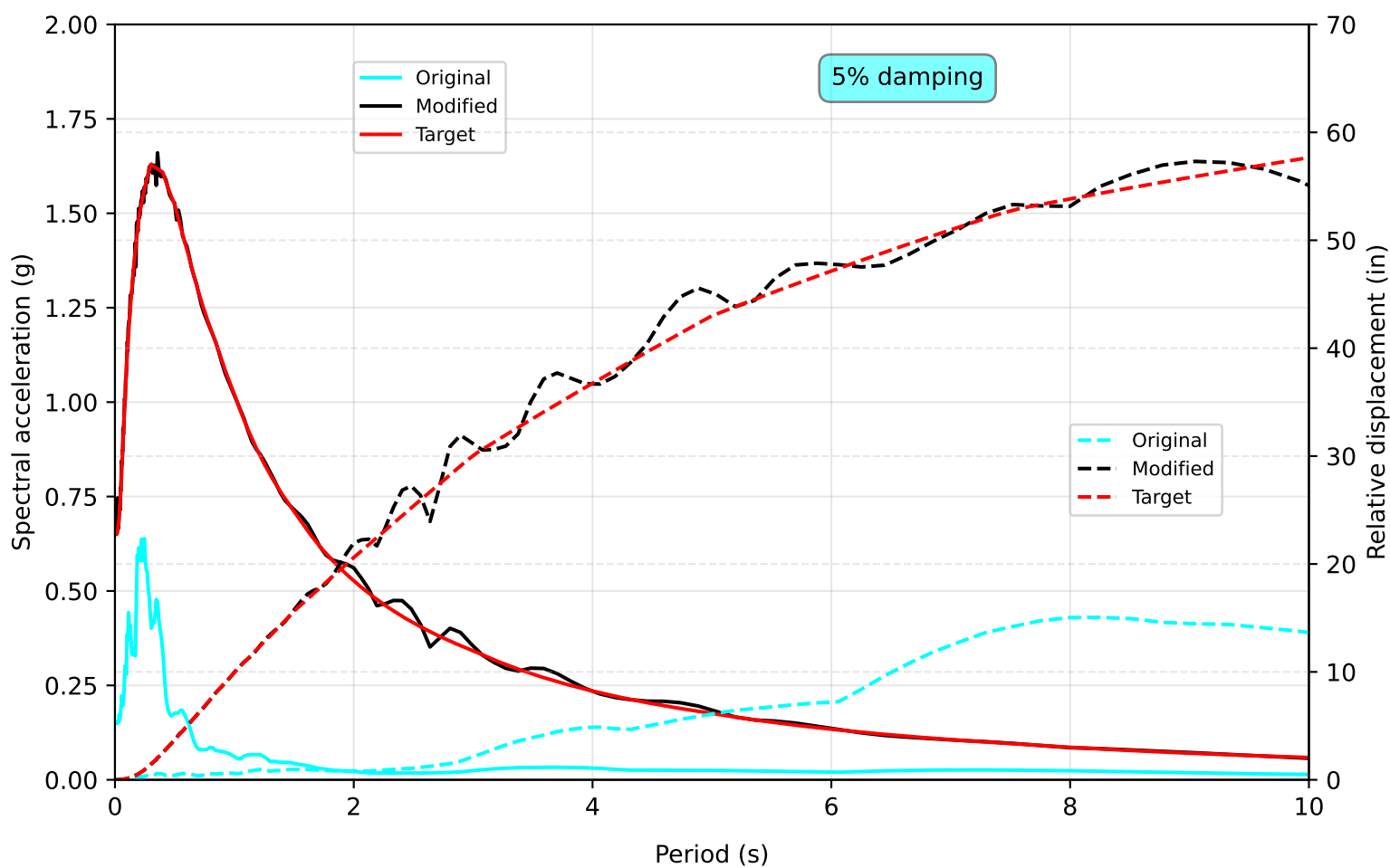
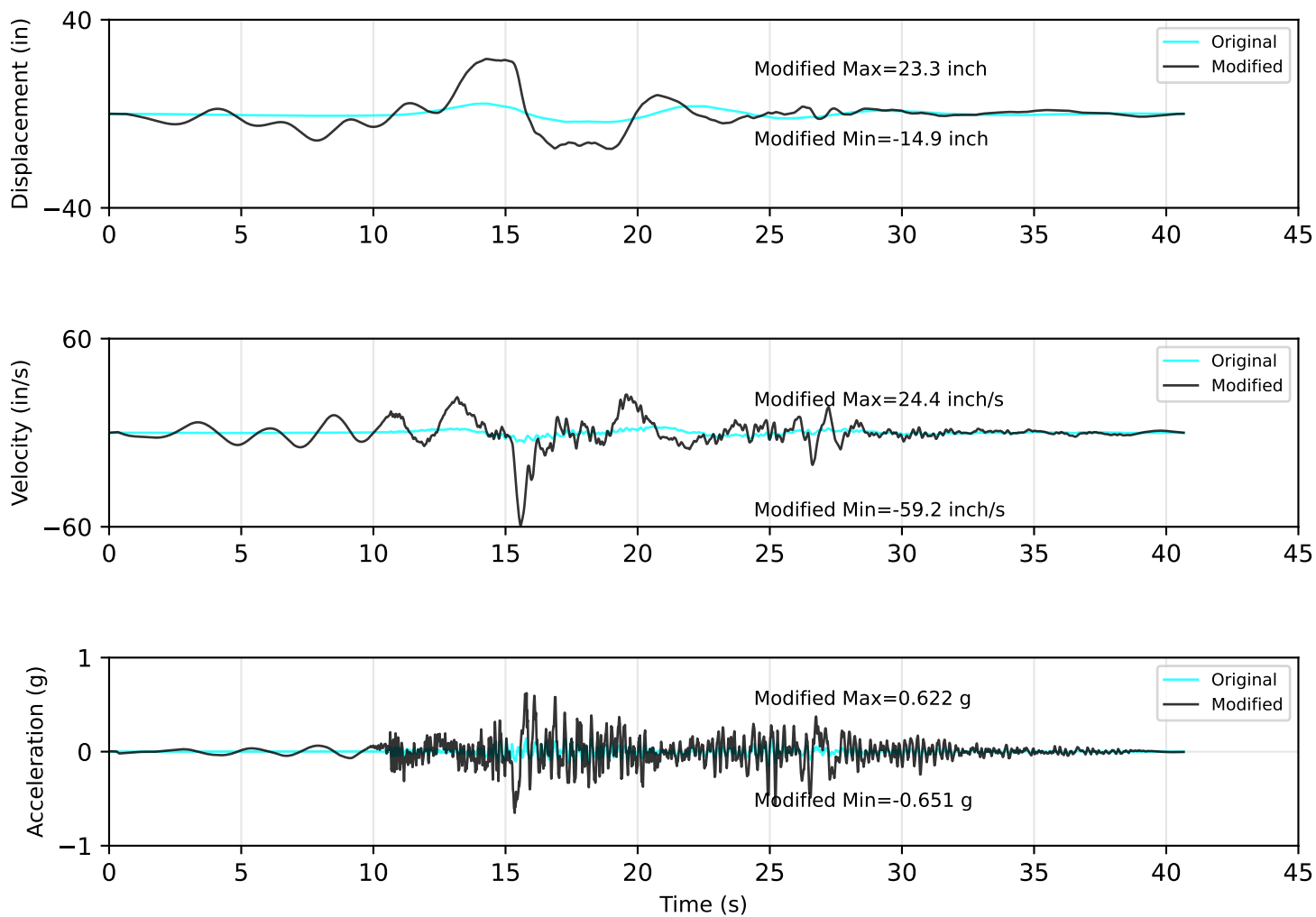


Figure E10. Firm (Improved) Ground ASCE 7-22 DE Spectrum-matched Ground Motion - Set-4-Fault Normal

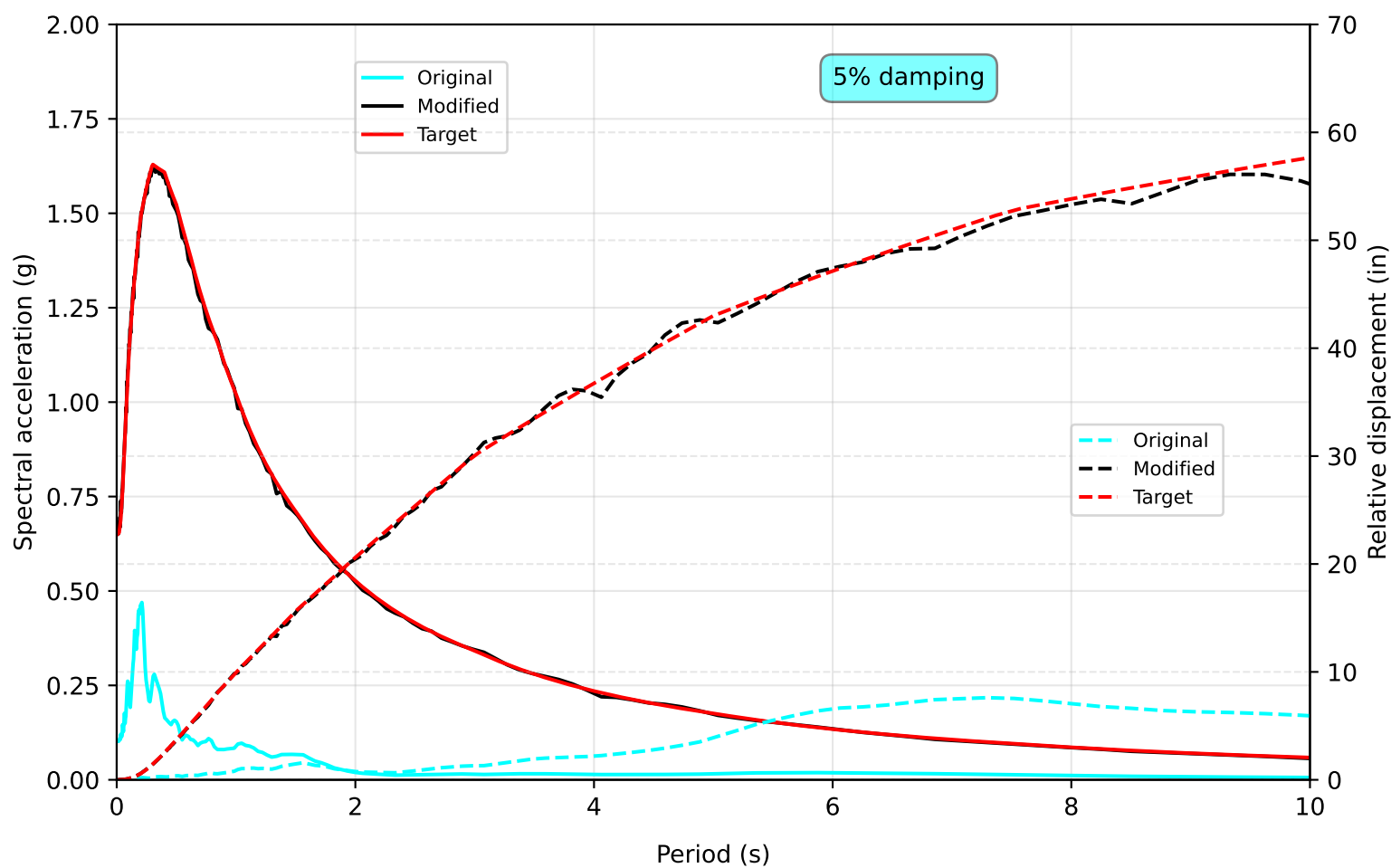
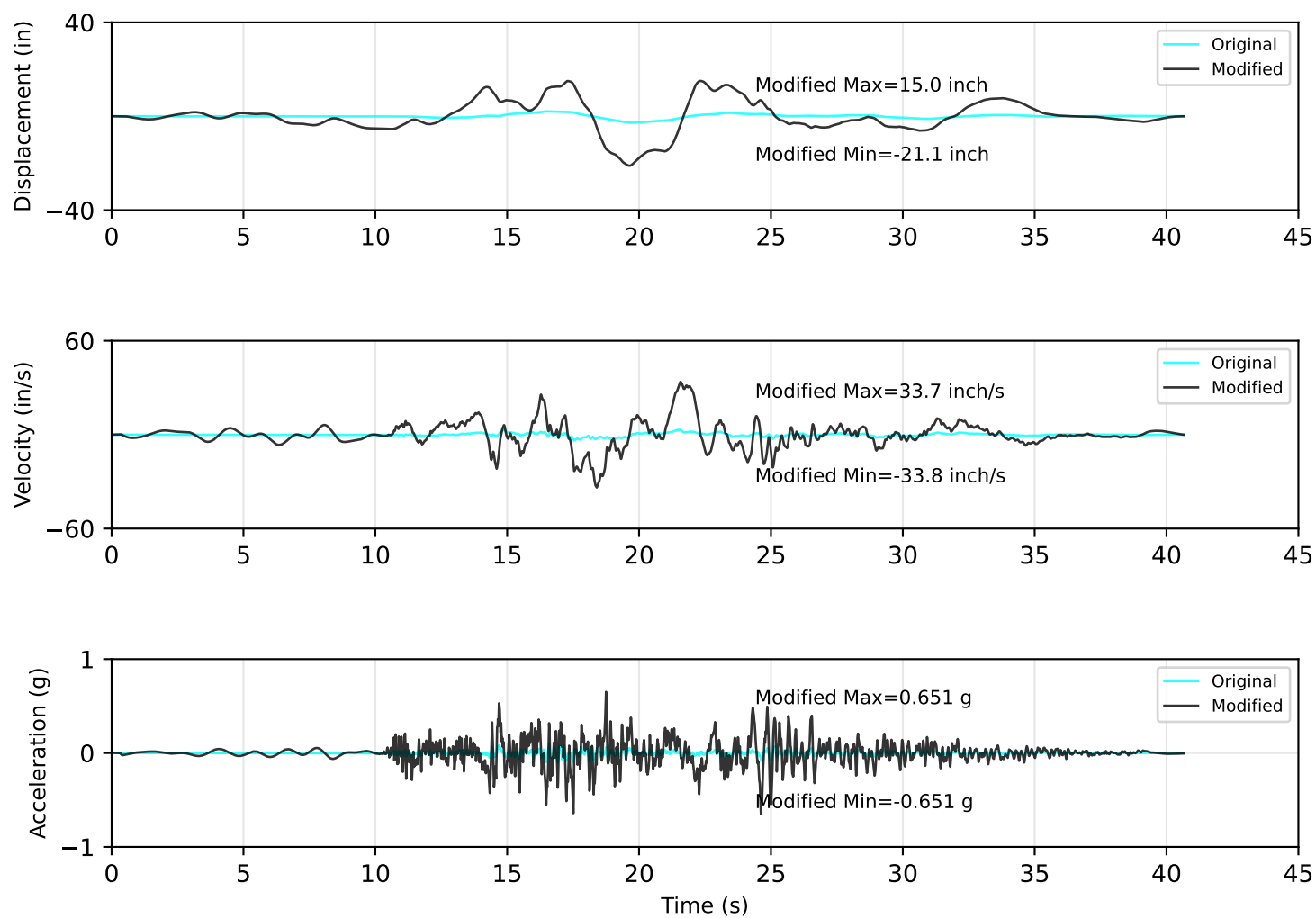


Figure E11. Firm (Improved) Ground ASCE 7-22 DE Spectrum-matched Ground Motion - Set-4-Fault Parallel

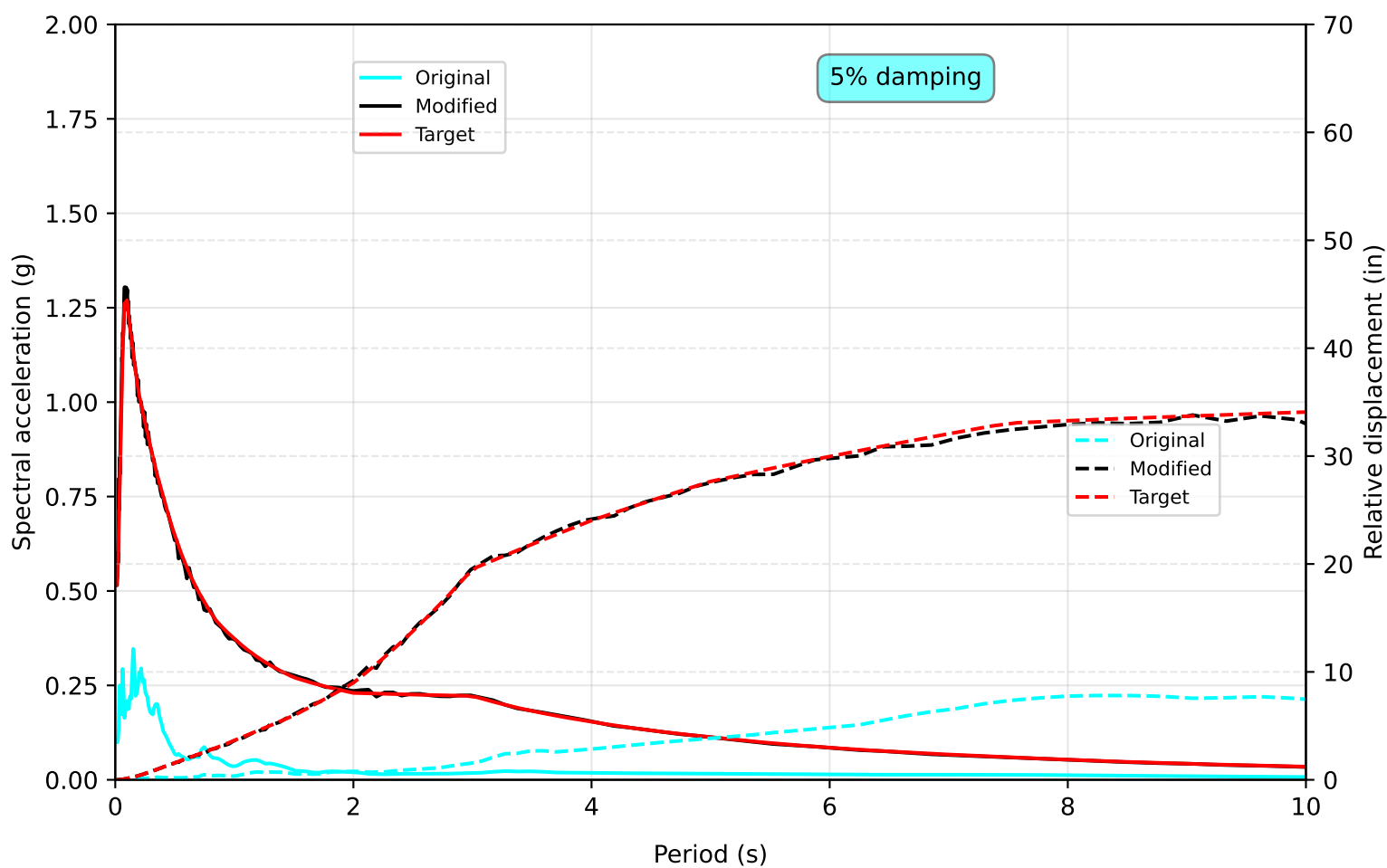
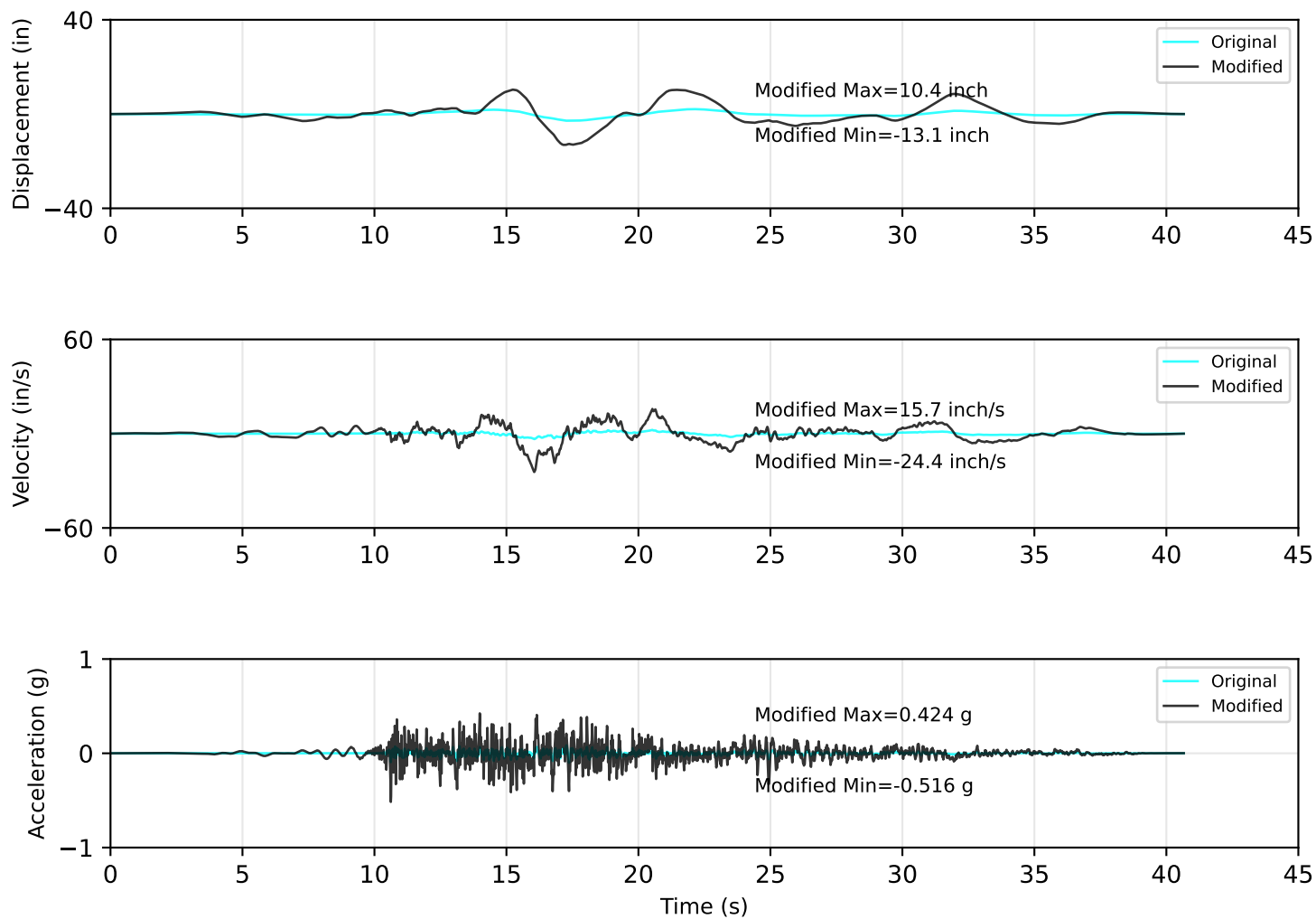


Figure E12. Firm (Improved) Ground ASCE 7-22 DE Spectrum-matched Ground Motion - Set-4 Vertical

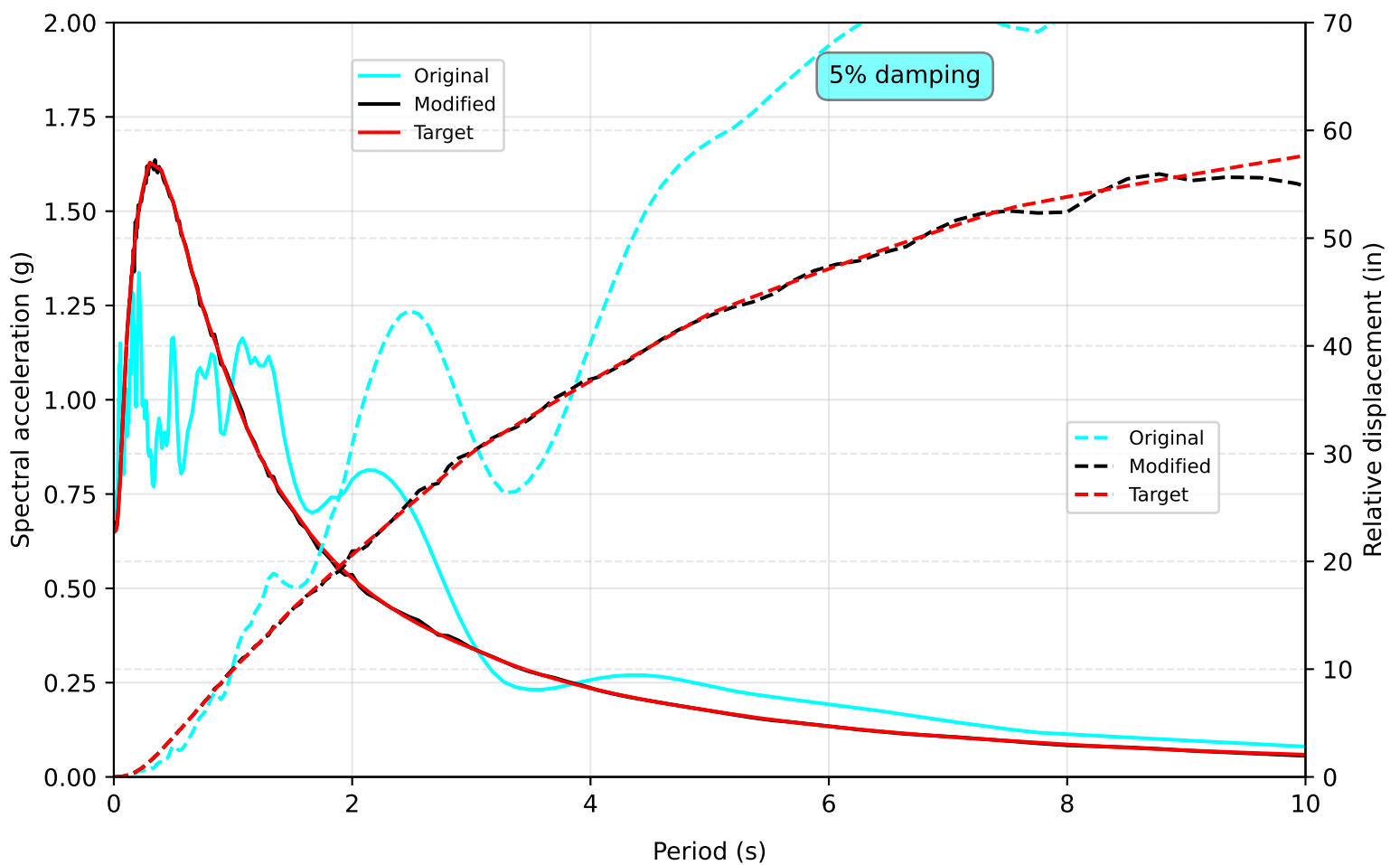
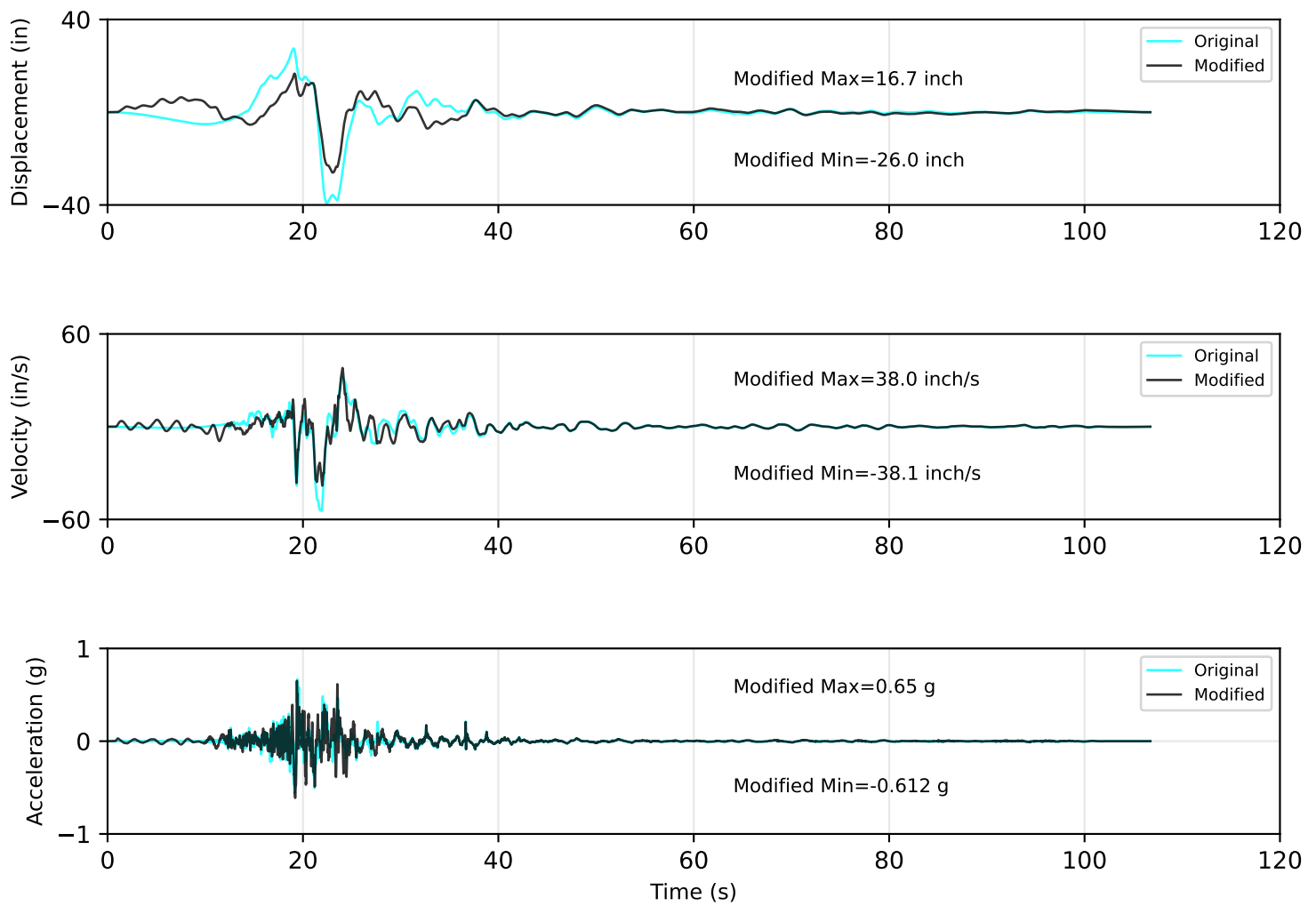


Figure E13. Firm (Improved) Ground ASCE 7-22 DE Spectrum-matched Ground Motion - Set-5-Fault Normal

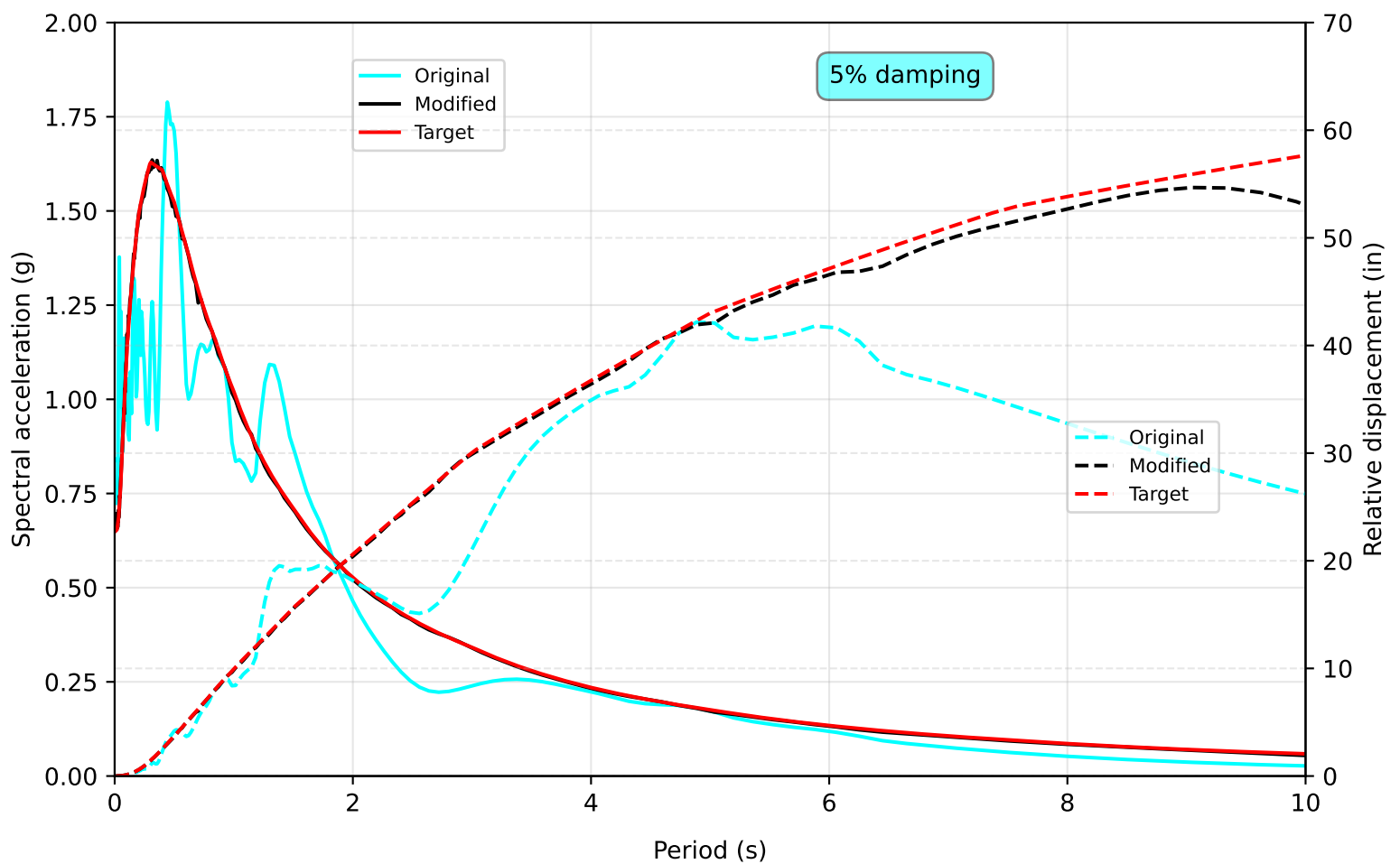
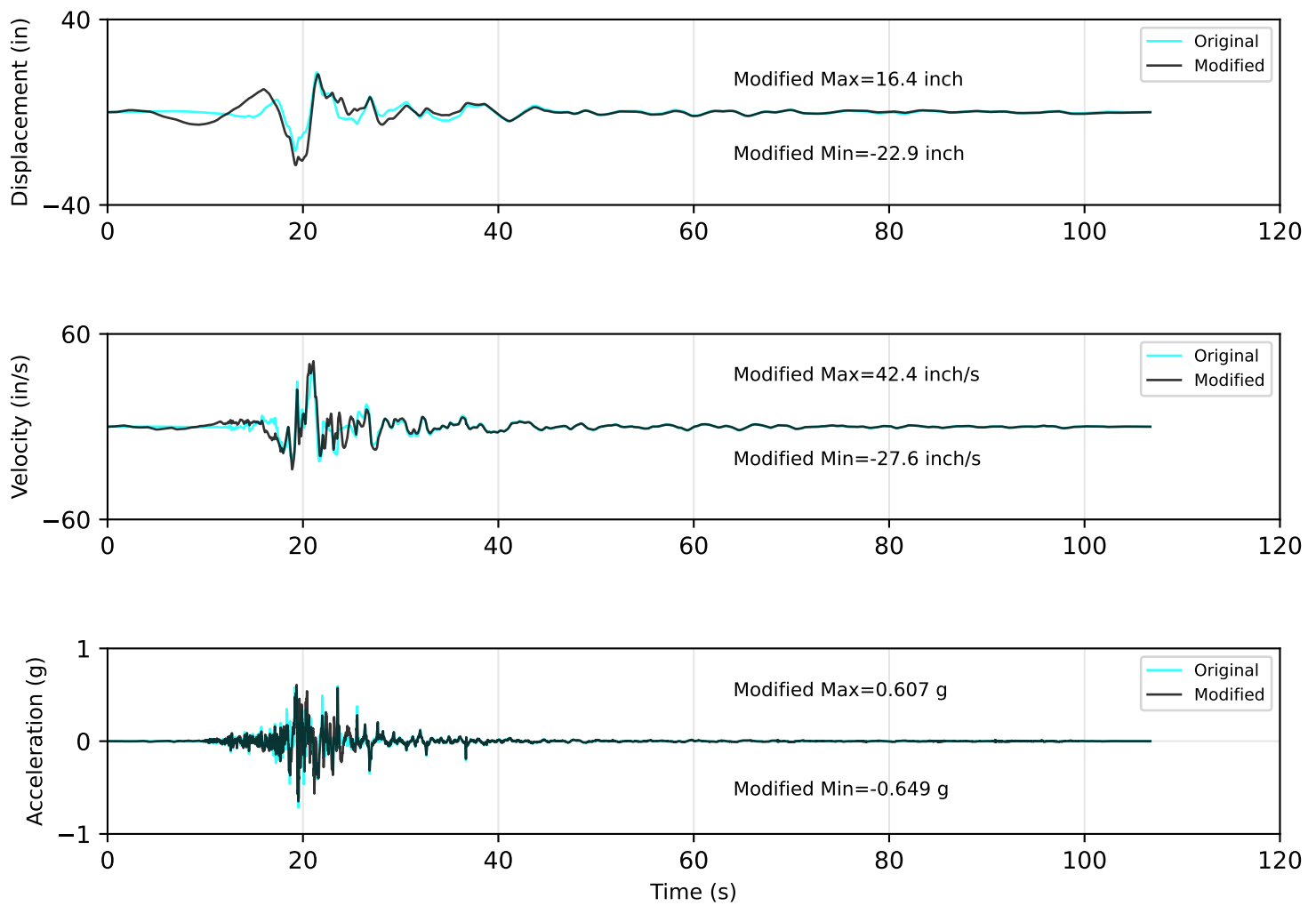


Figure E14. Firm (Improved) Ground ASCE 7-22 DE Spectrum-matched Ground Motion - Set-5-Fault Parallel

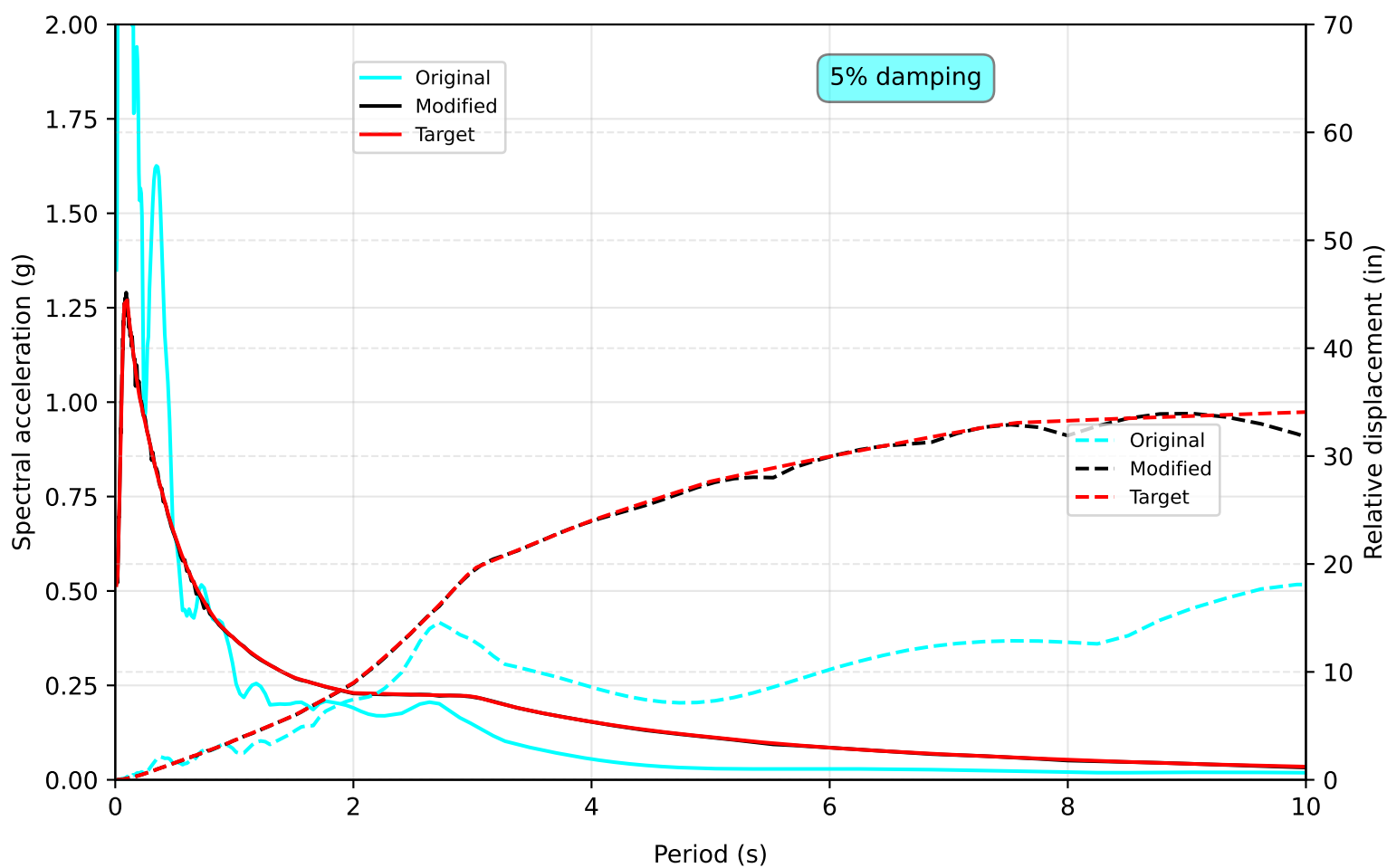
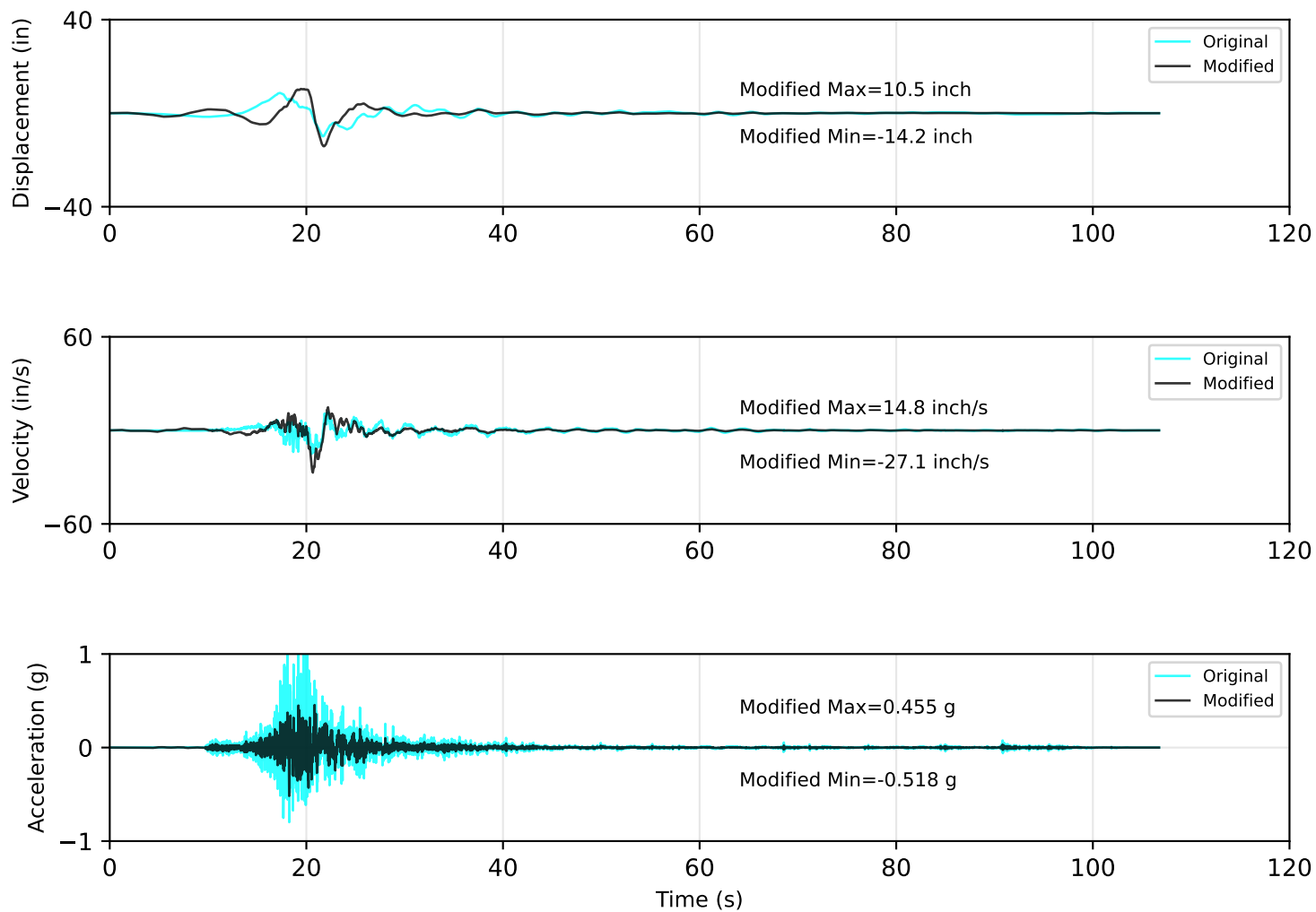


Figure E15. Firm (Improved) Ground ASCE 7-22 DE Spectrum-matched Ground Motion - Set-5 Vertical

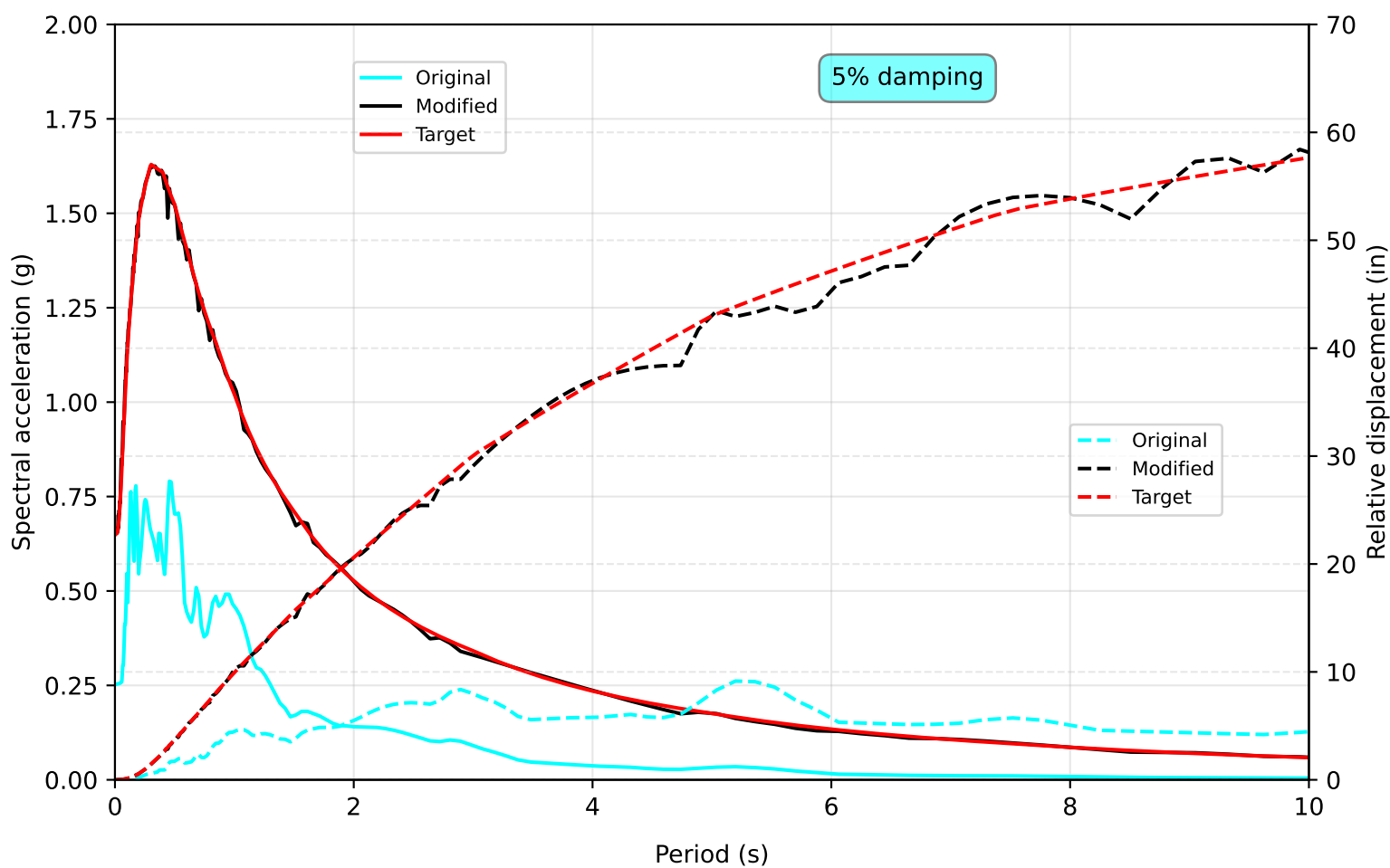
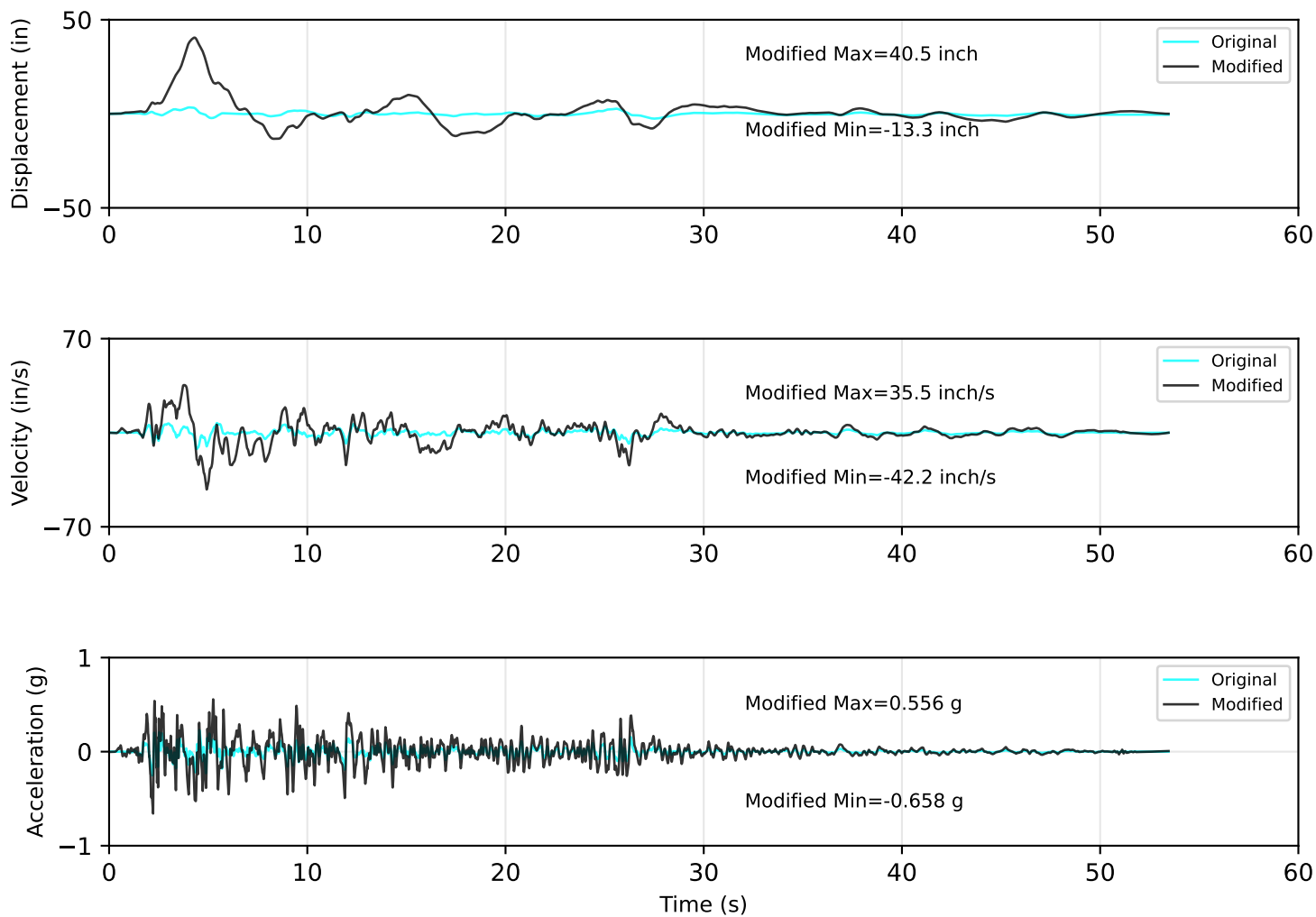


Figure E16. Firm (Improved) Ground ASCE 7-22 DE Spectrum-matched Ground Motion - Set-6-Fault Normal

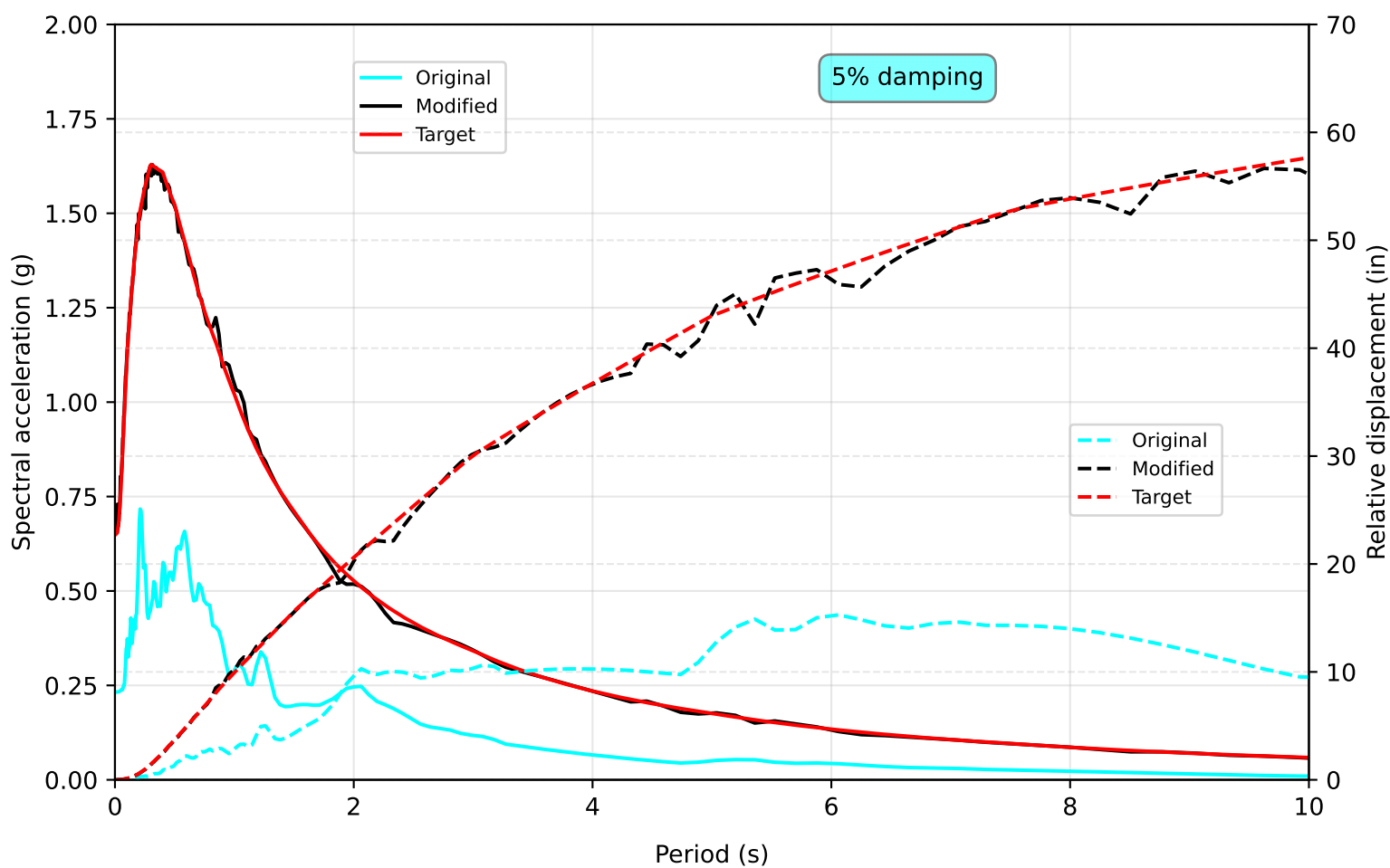
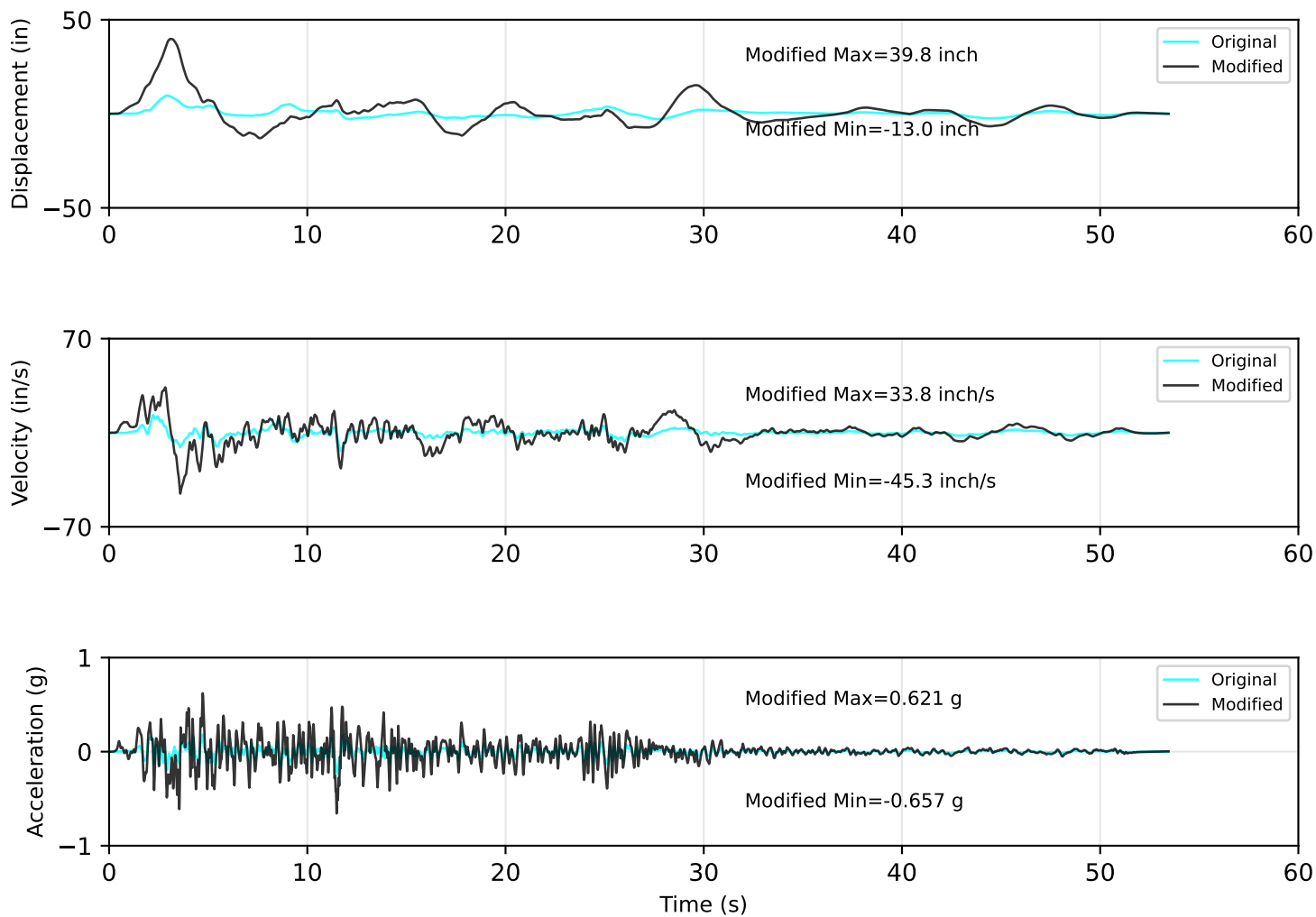


Figure E17. Firm (Improved) Ground ASCE 7-22 DE Spectrum-matched Ground Motion - Set-6-Fault Parallel

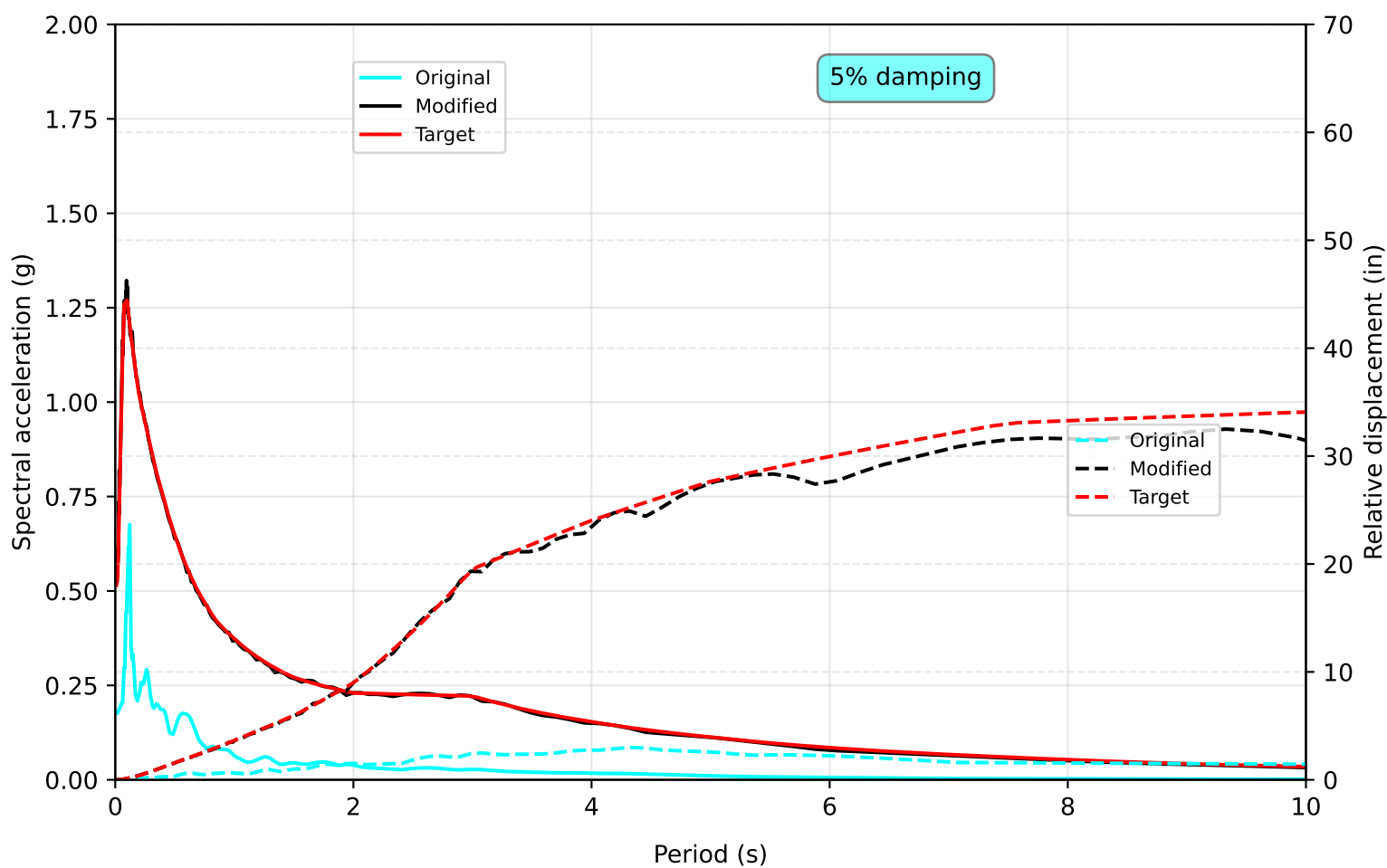
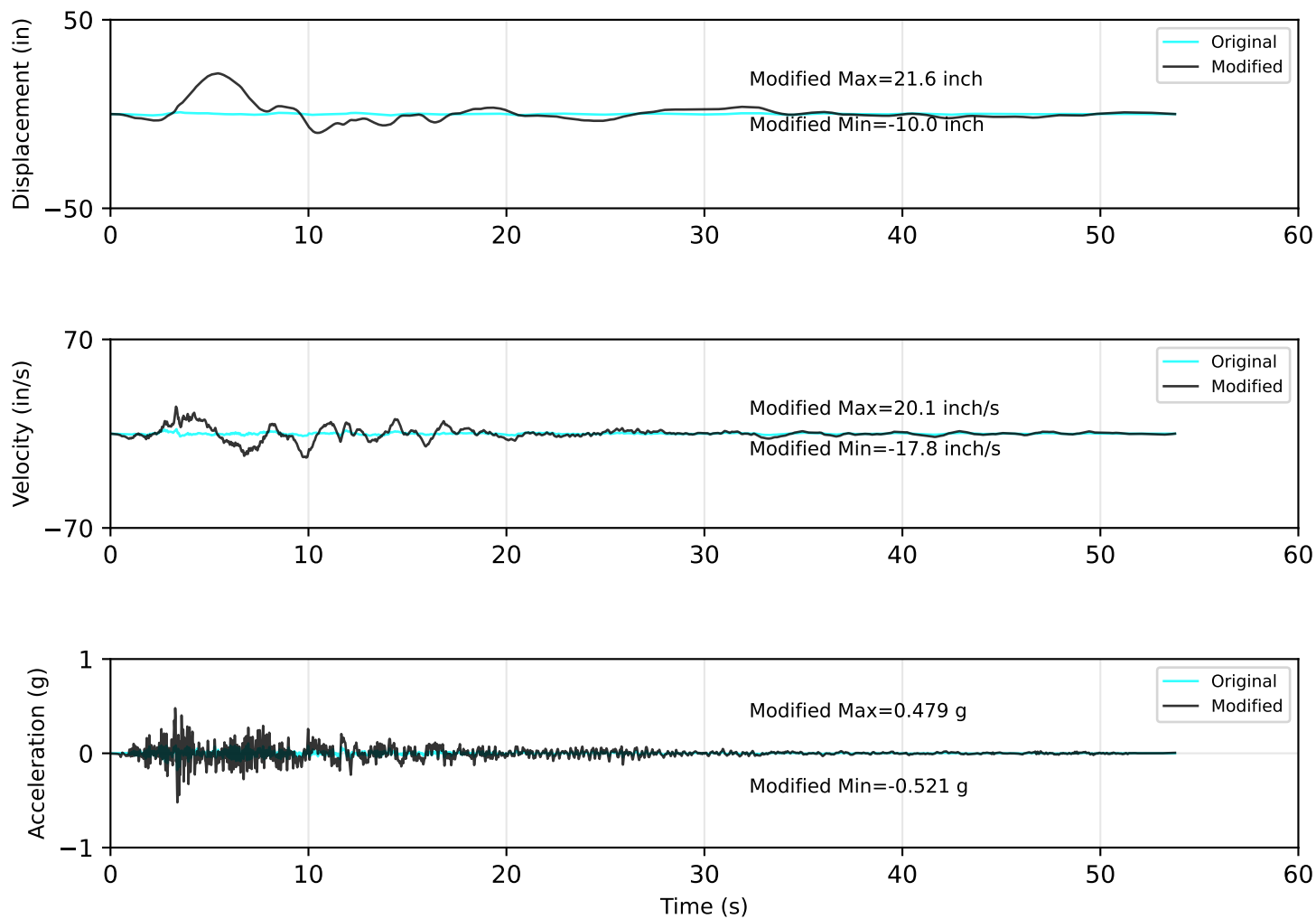


Figure E18. Firm (Improved) Ground ASCE 7-22 DE Spectrum-matched Ground Motion - Set-6 Vertical

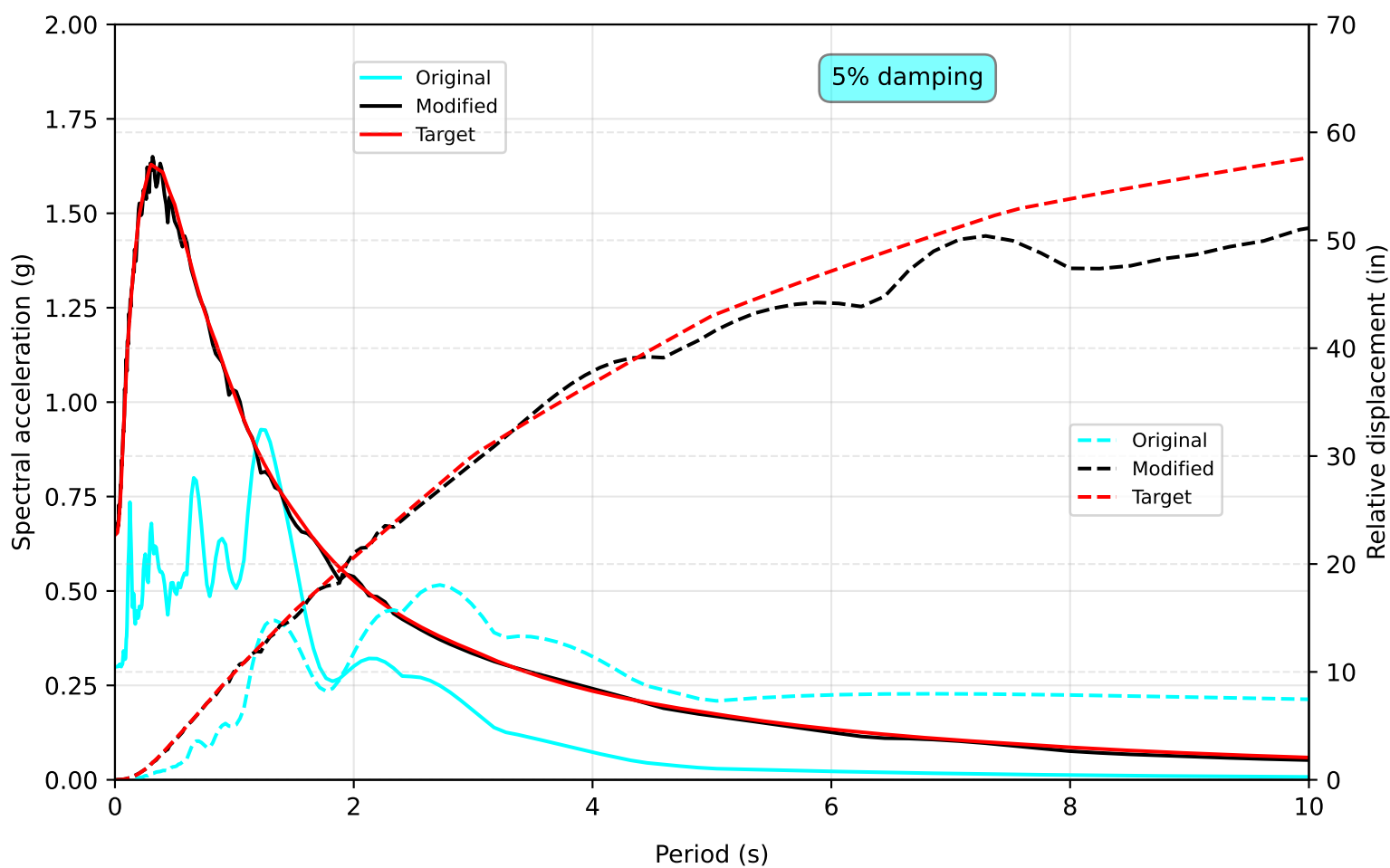
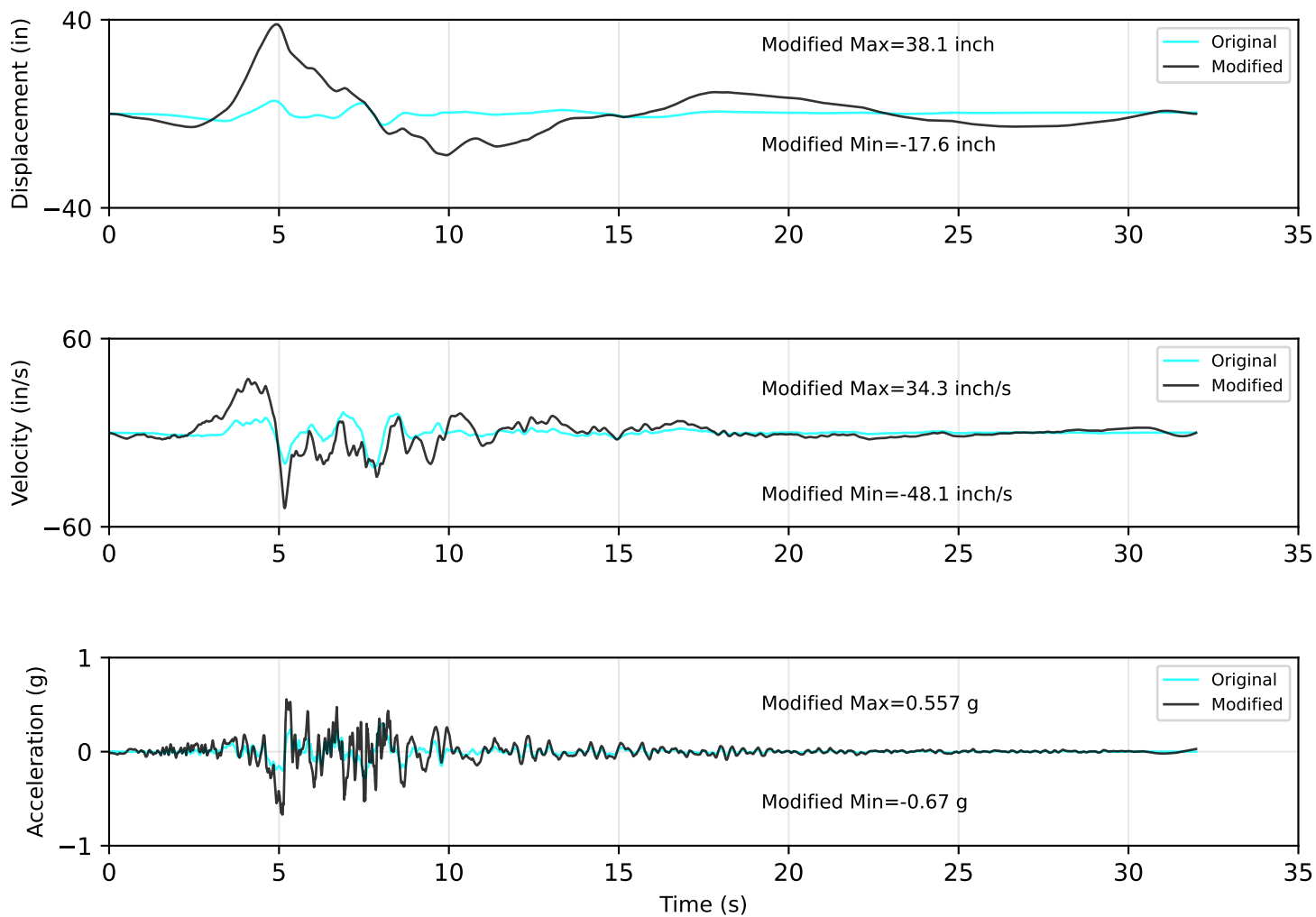


Figure E19. Firm (Improved) Ground ASCE 7-22 DE Spectrum-matched Ground Motion - Set-7-Fault Normal

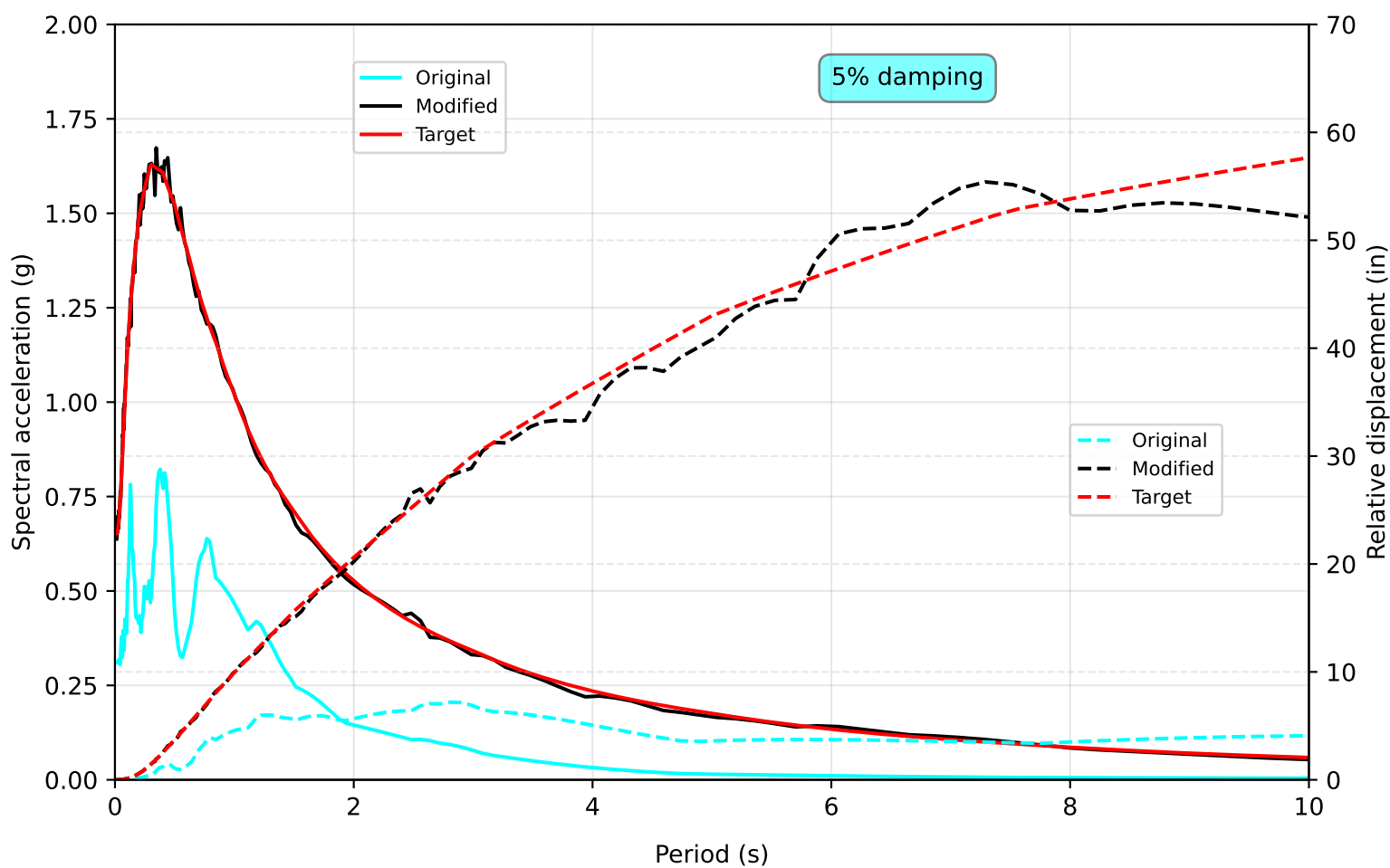
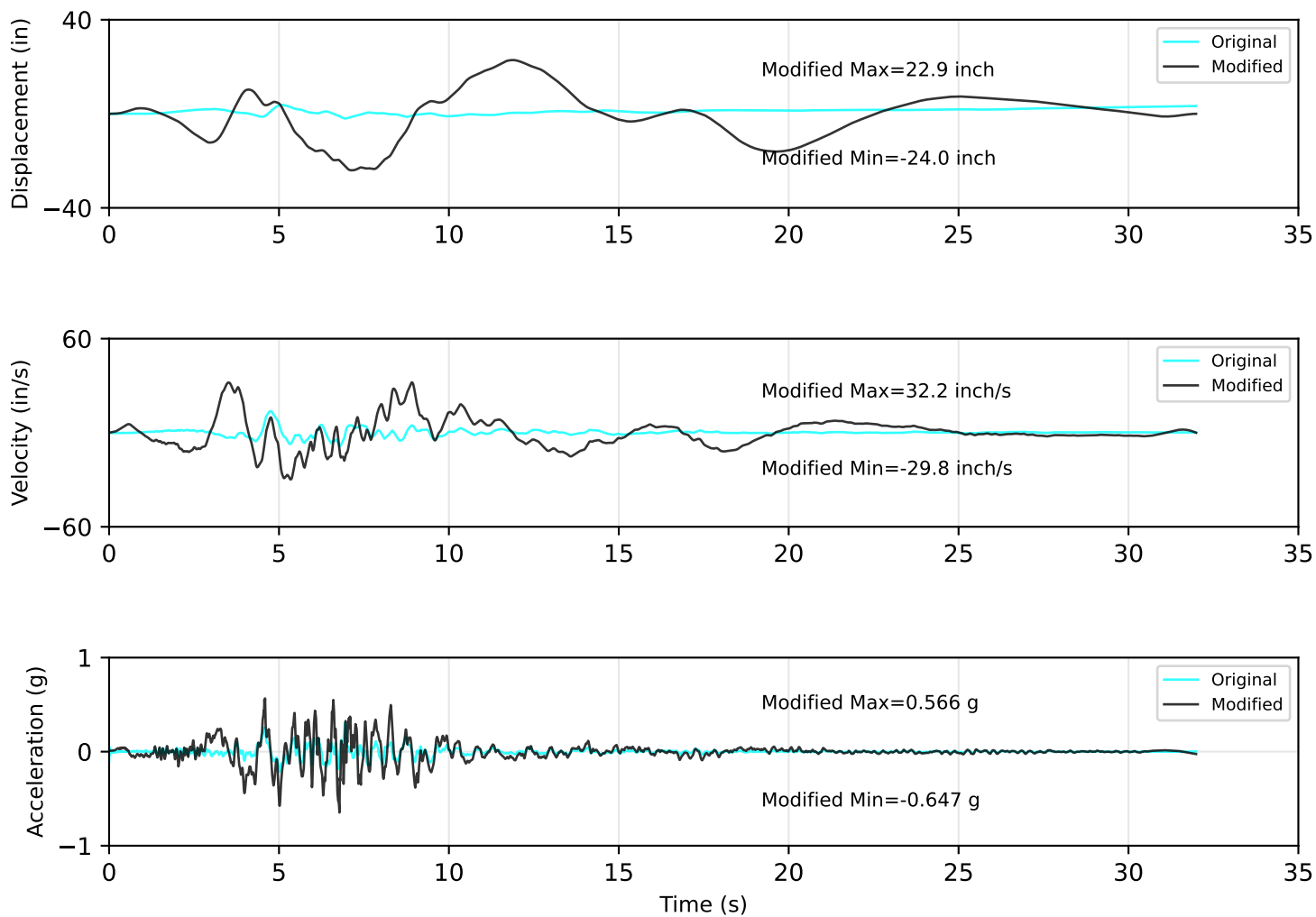


Figure E20. Firm (Improved) Ground ASCE 7-22 DE Spectrum-matched Ground Motion - Set-7-Fault Parallel

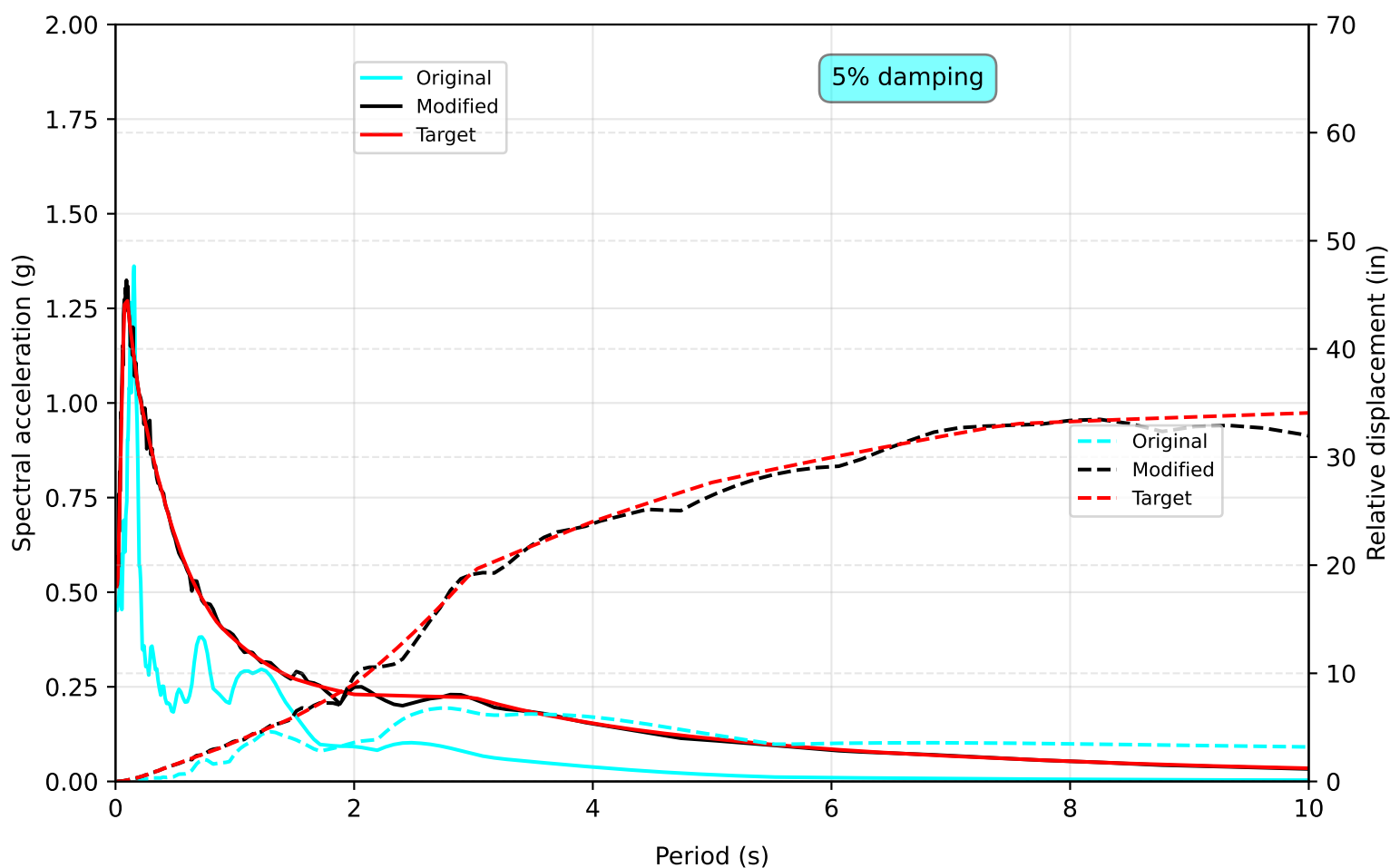
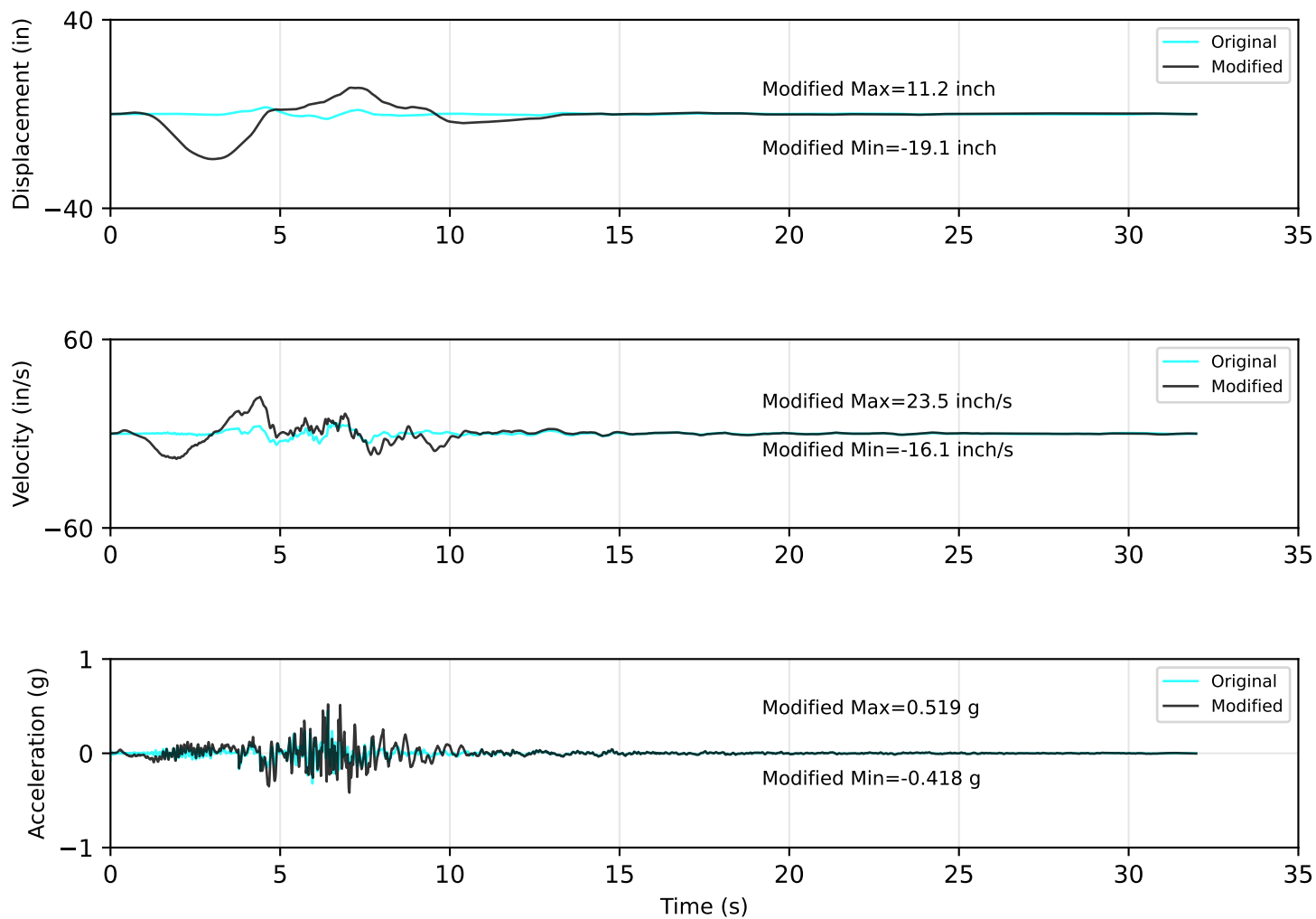


Figure E21. Firm (Improved) Ground ASCE 7-22 DE Spectrum-matched Ground Motion - Set-7 Vertical

PART II:
SPECTRUM-MATCHED GROUND MOTIONS FOR DE FOR UNIMPROVED
GROUND CONDITION

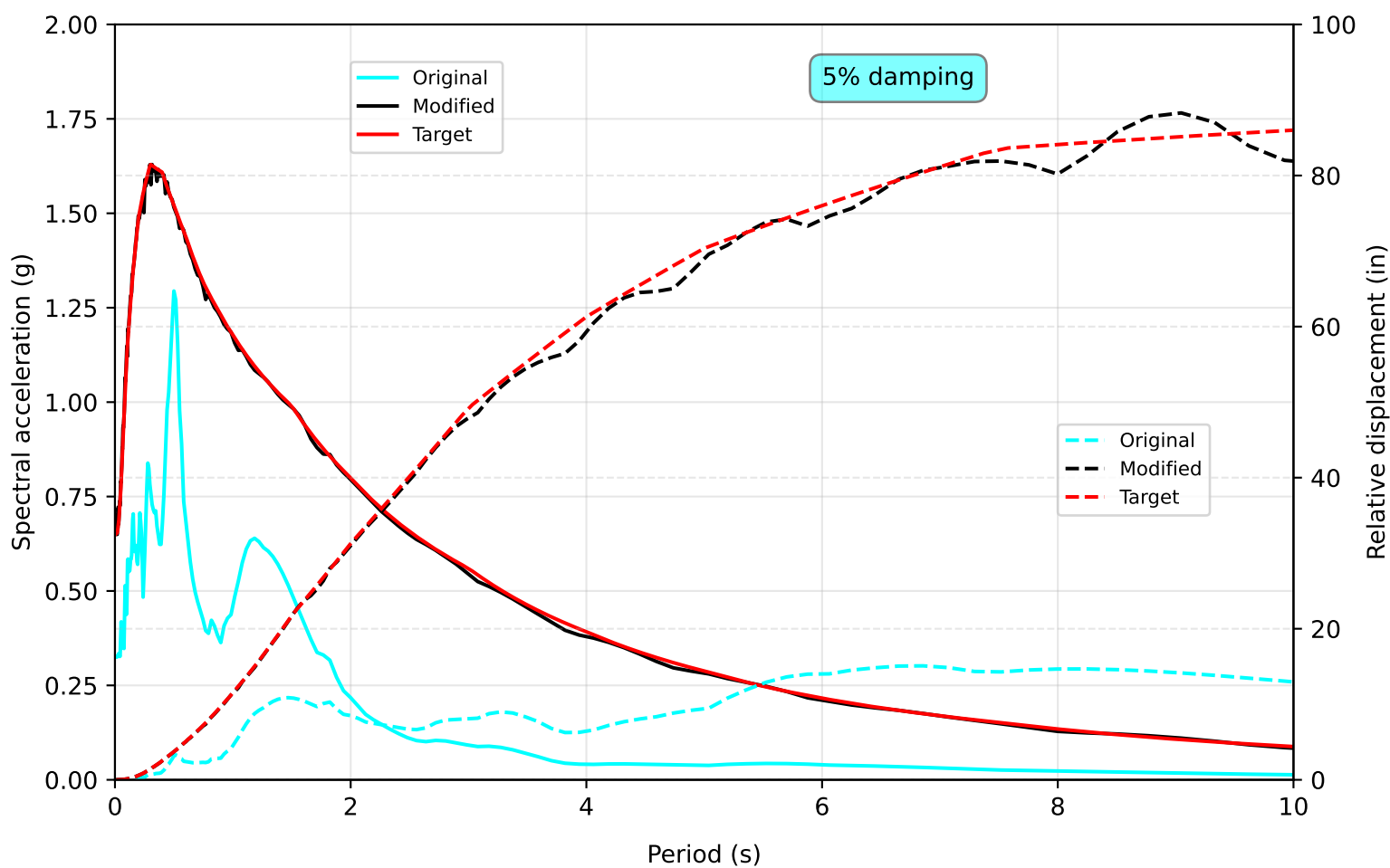
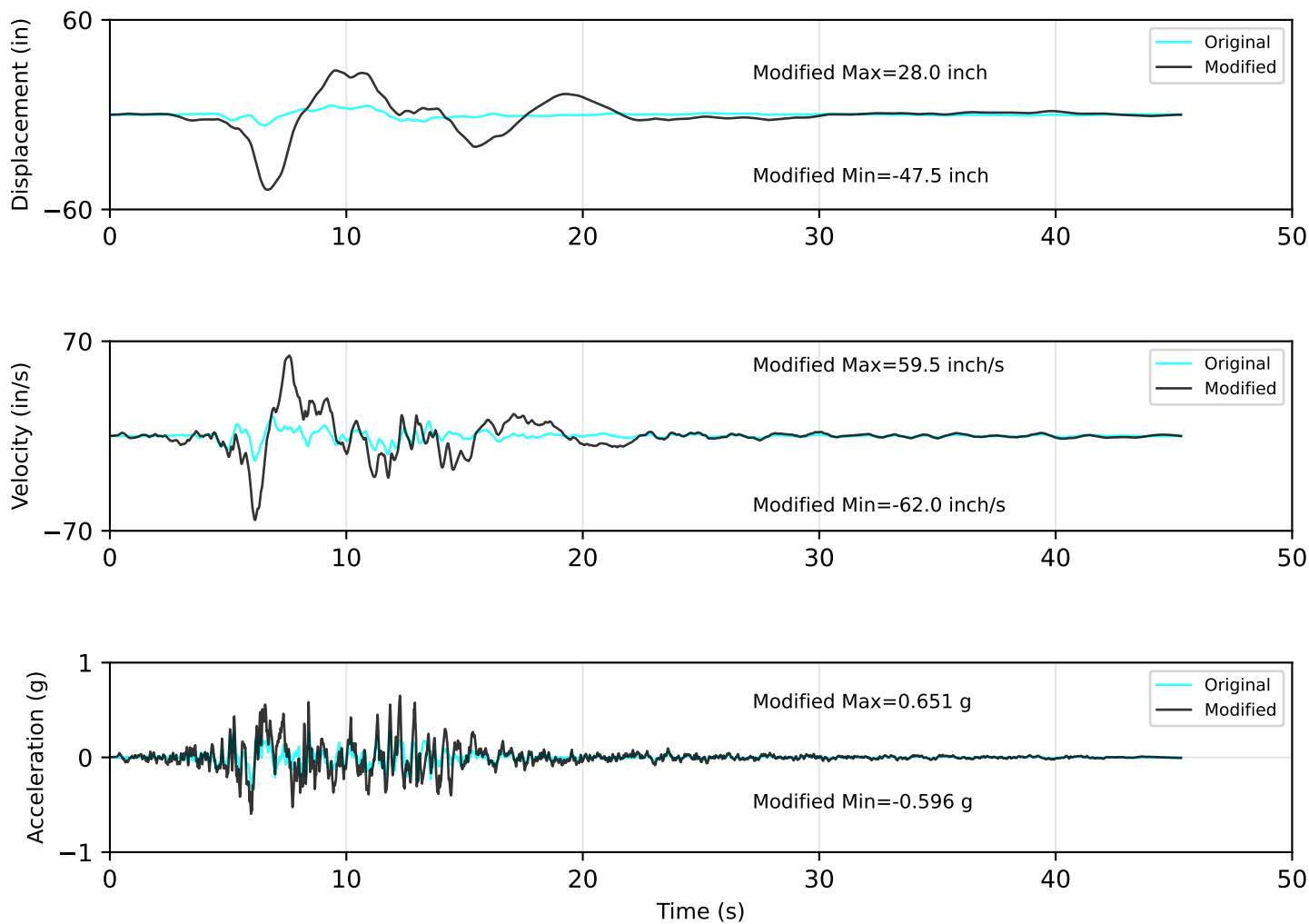


Figure E22. Unimproved Ground ASCE 7-22 DE Spectrum-matched Ground Motion - Set-1-Fault Normal

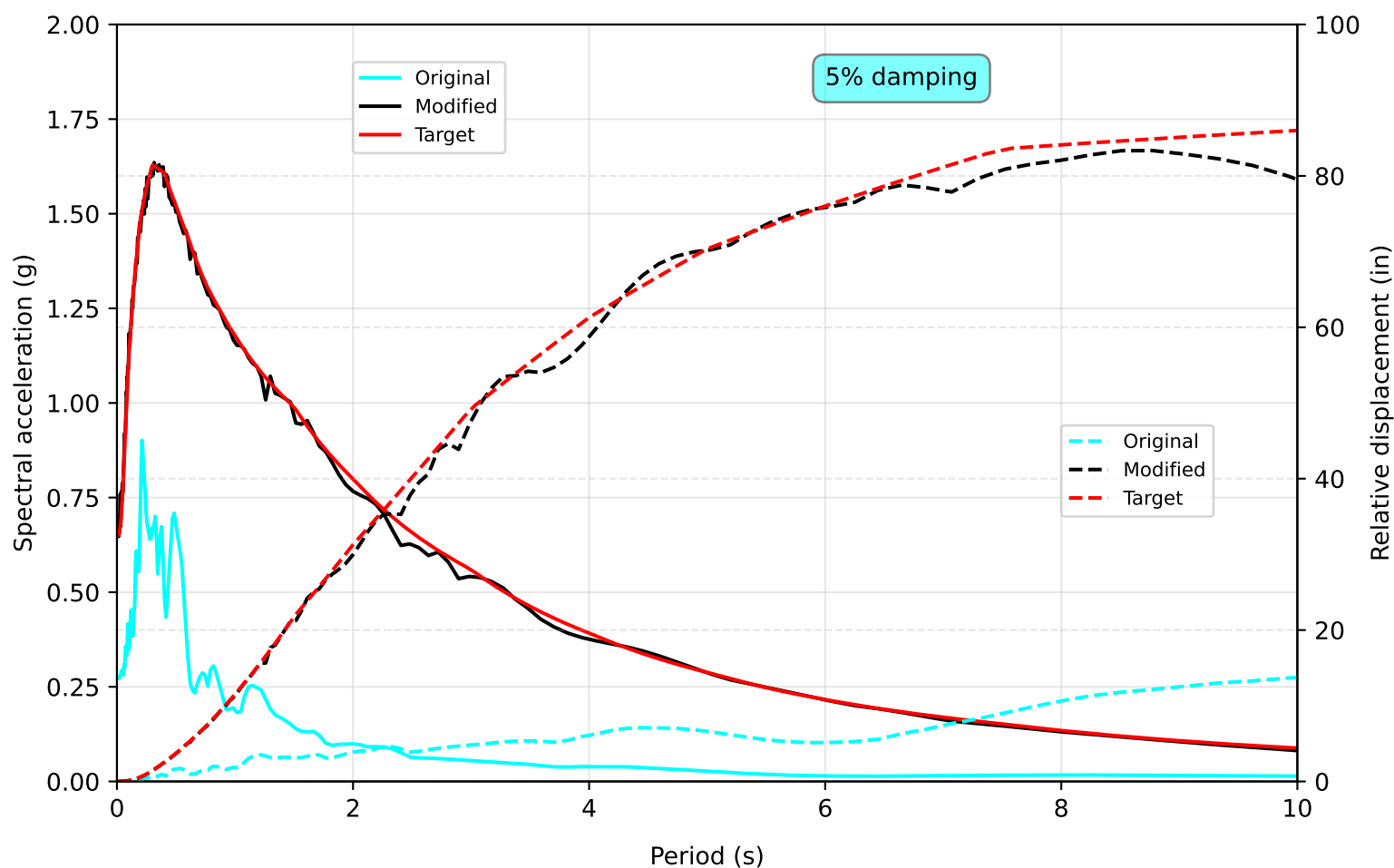
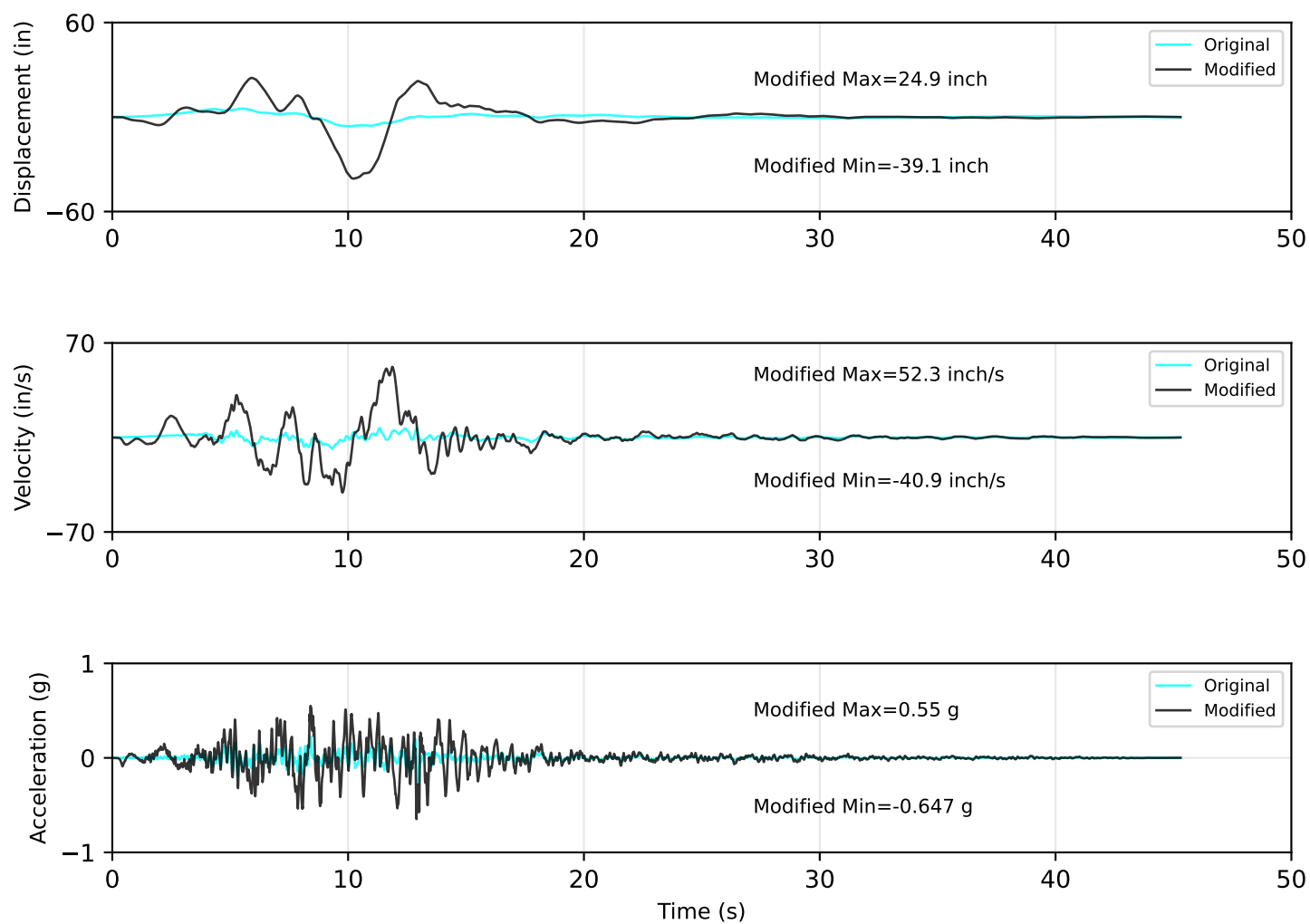


Figure E23. Unimproved Ground ASCE 7-22 DE Spectrum-matched Ground Motion - Set-1-Fault Parallel

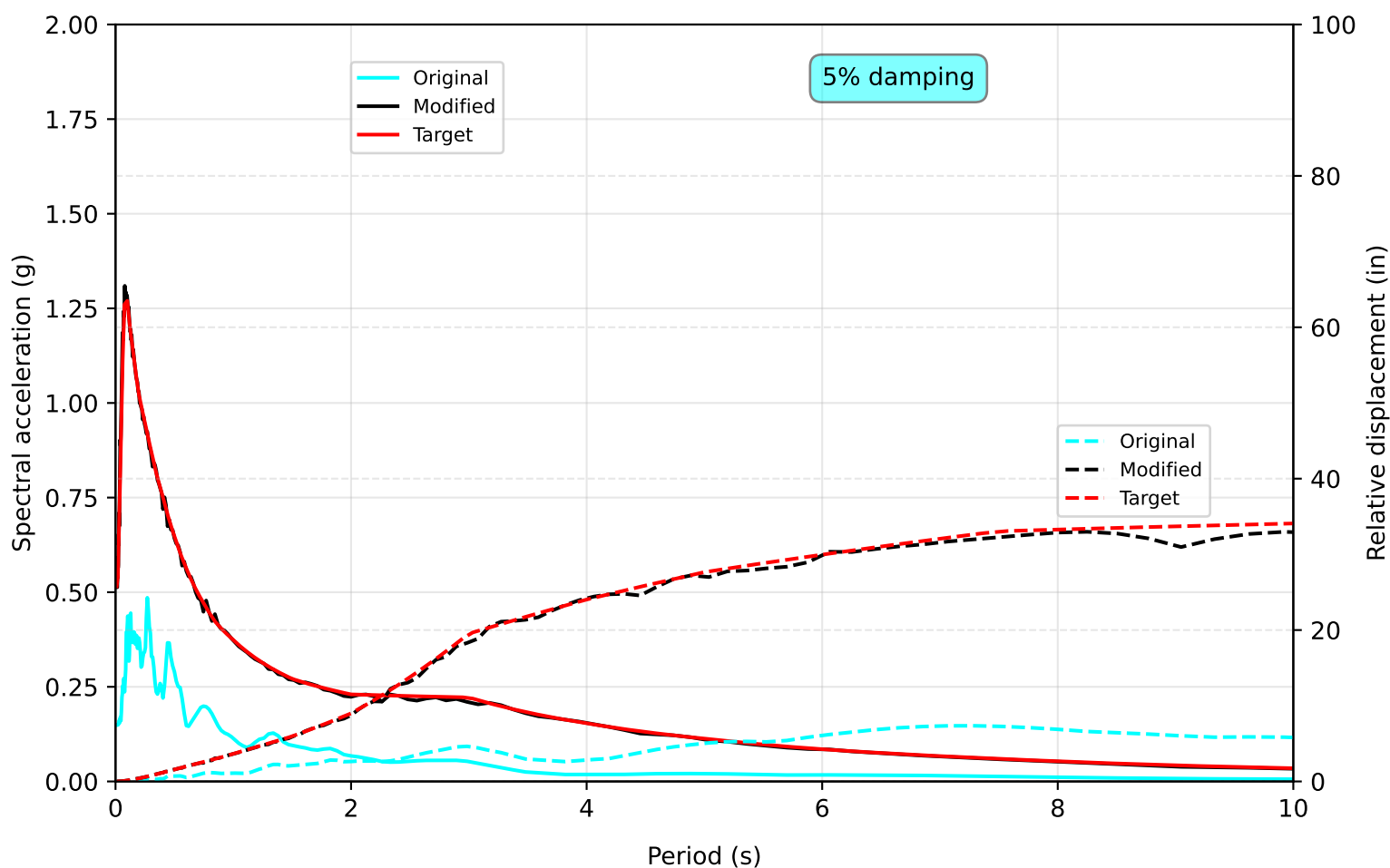
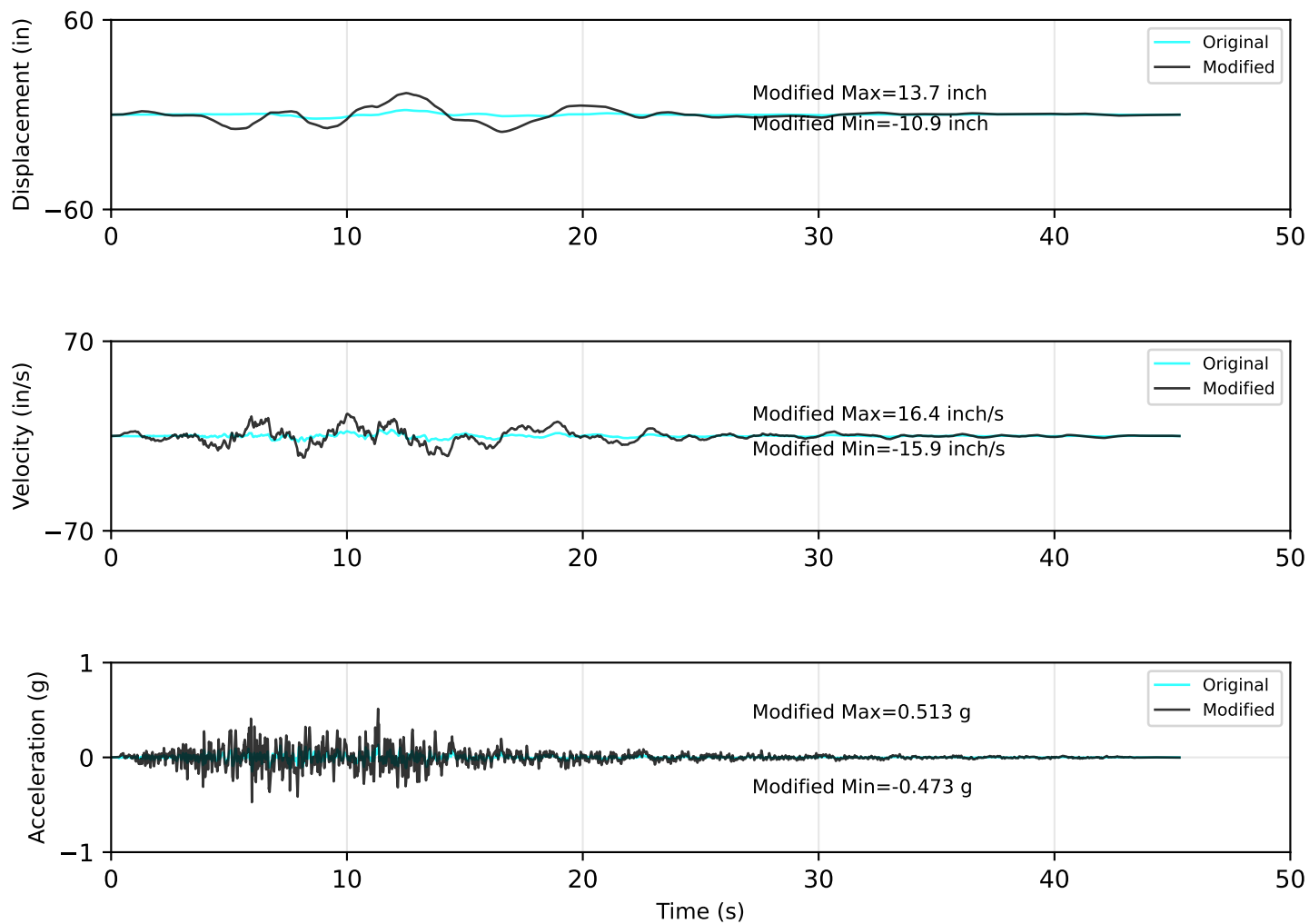


Figure E24. Unimproved Ground ASCE 7-22 DE Spectrum-matched Ground Motion - Set-1 Vertical

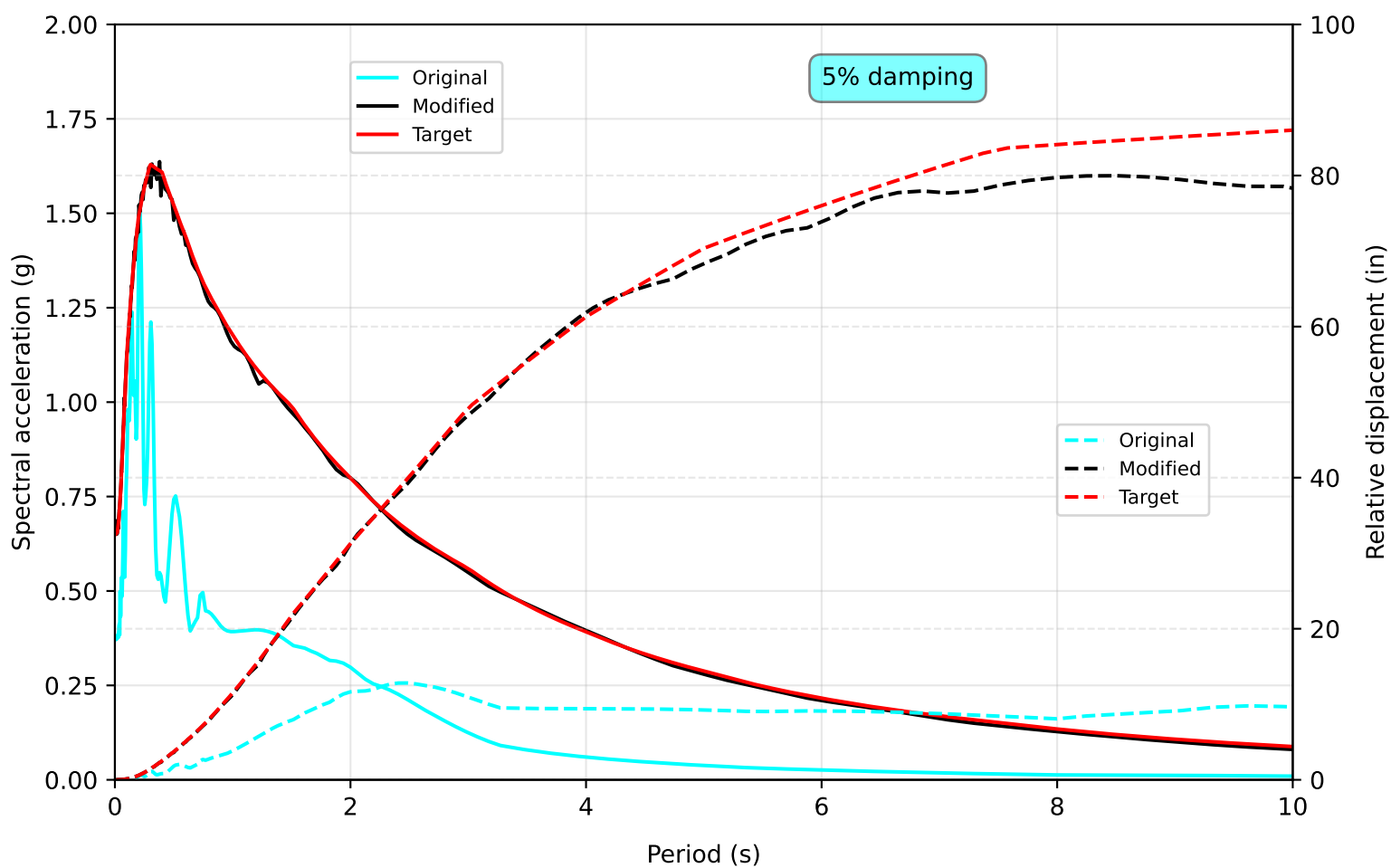
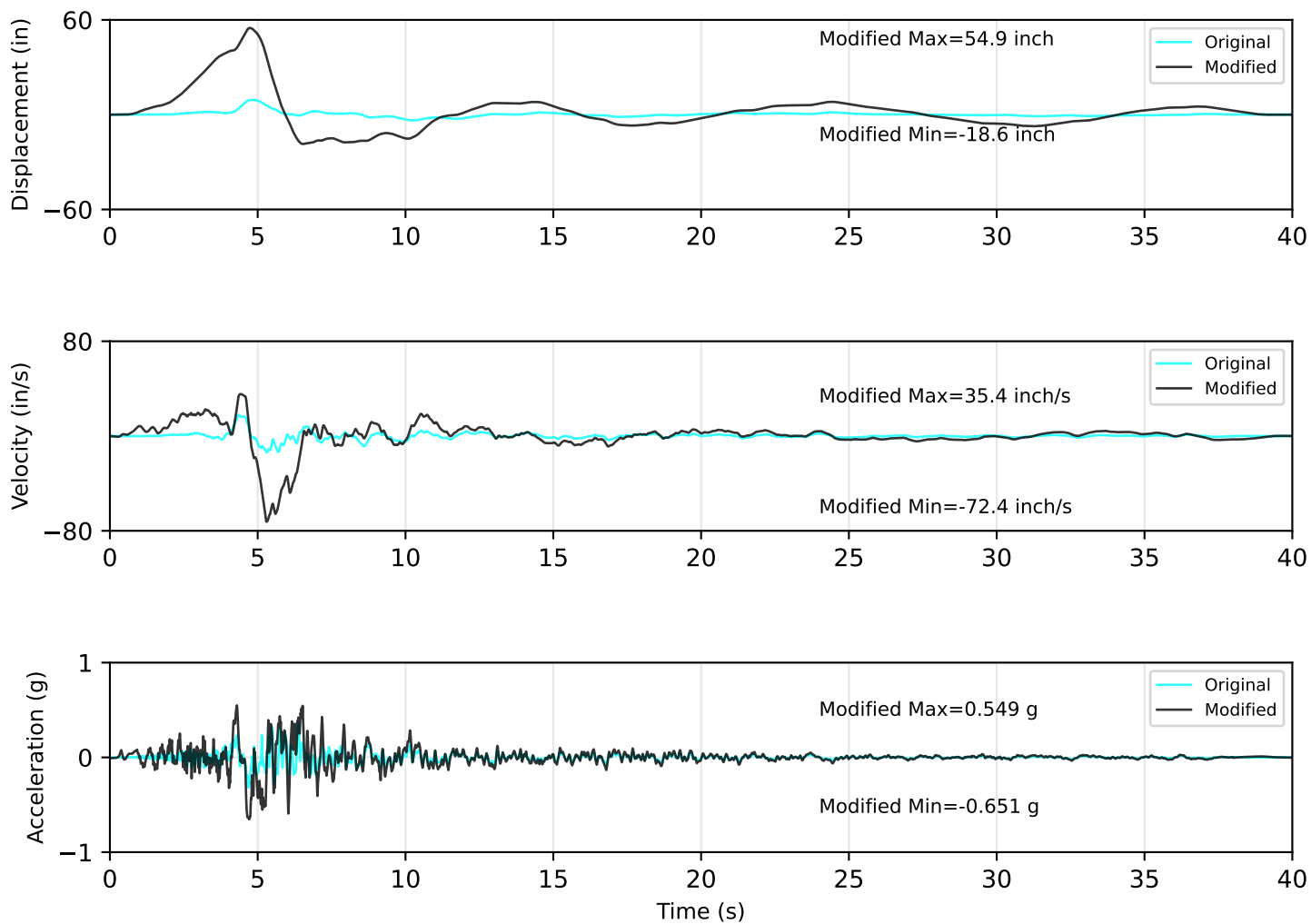


Figure E25. Unimproved Ground ASCE 7-22 DE Spectrum-matched Ground Motion - Set-2-Fault Normal

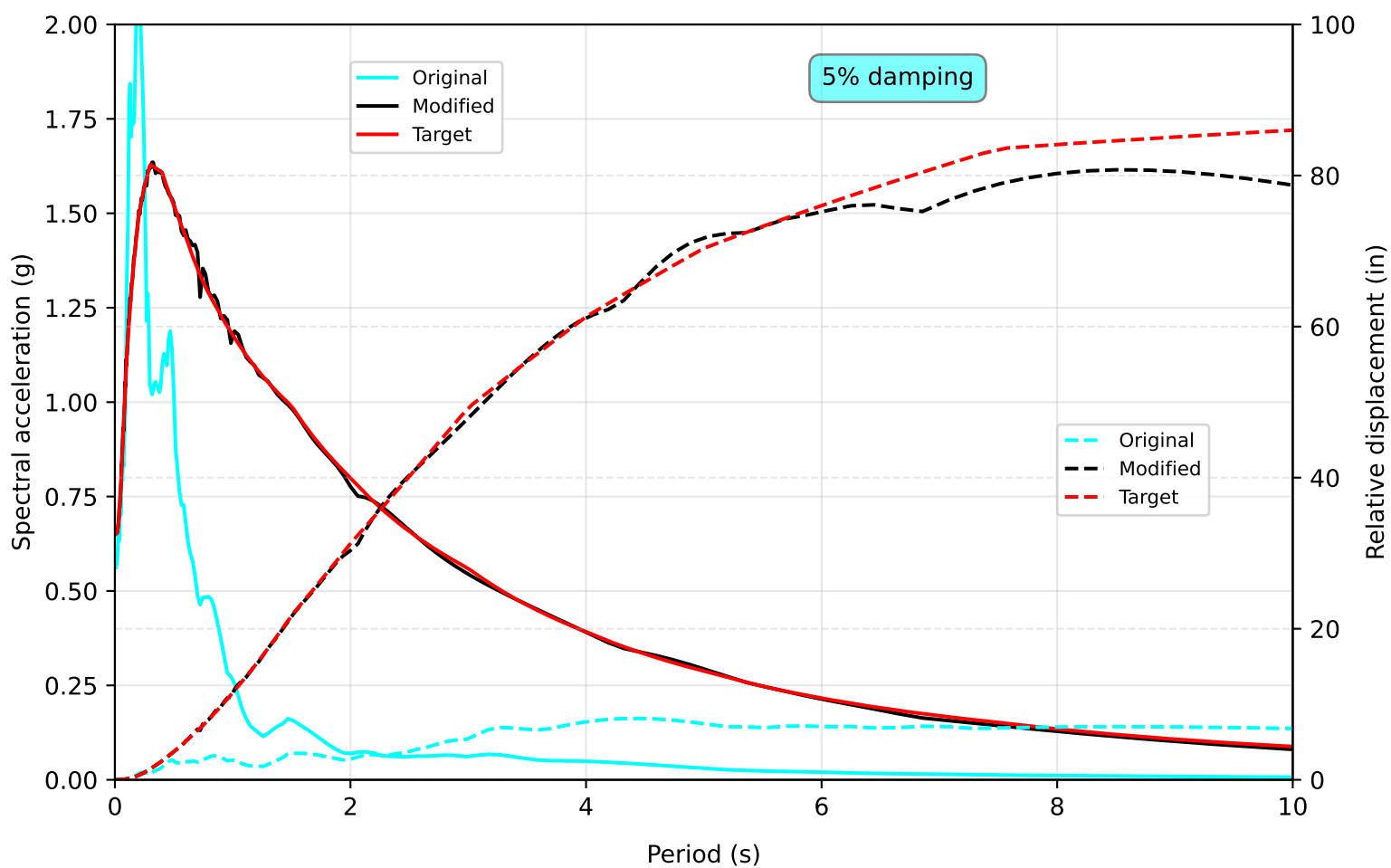
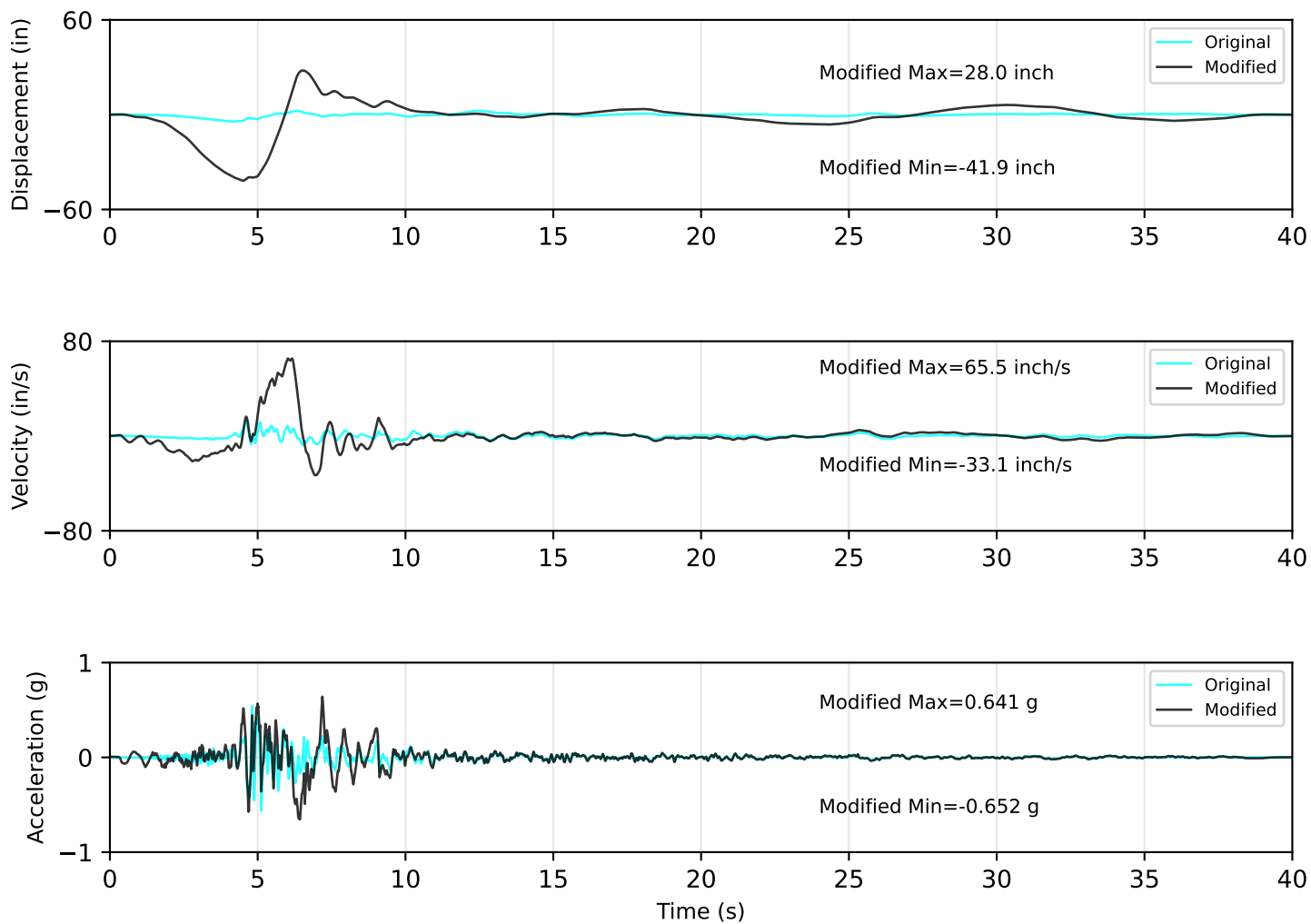


Figure E26. Unimproved Ground ASCE 7-22 DE Spectrum-matched Ground Motion - Set-2-Fault Parallel

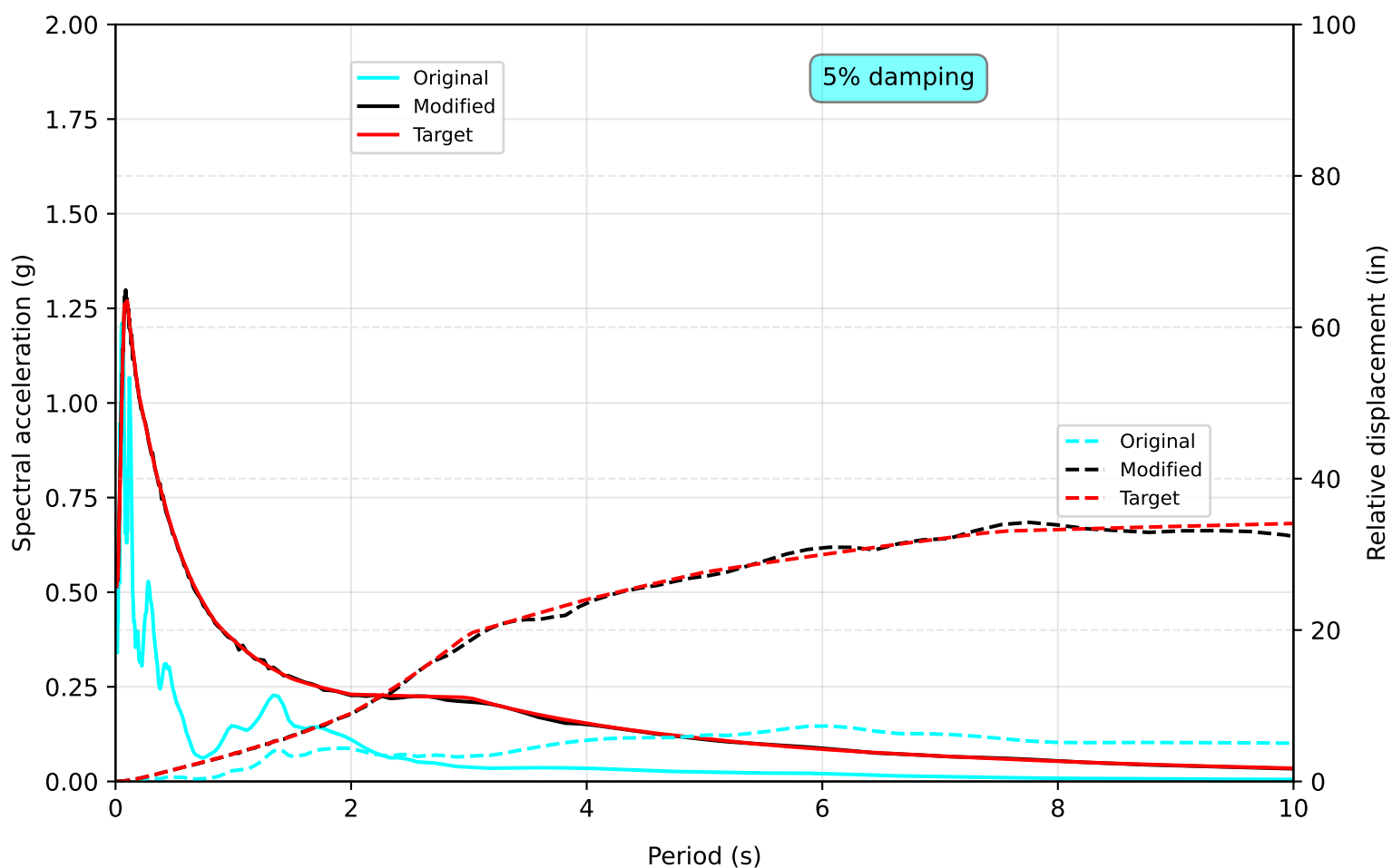
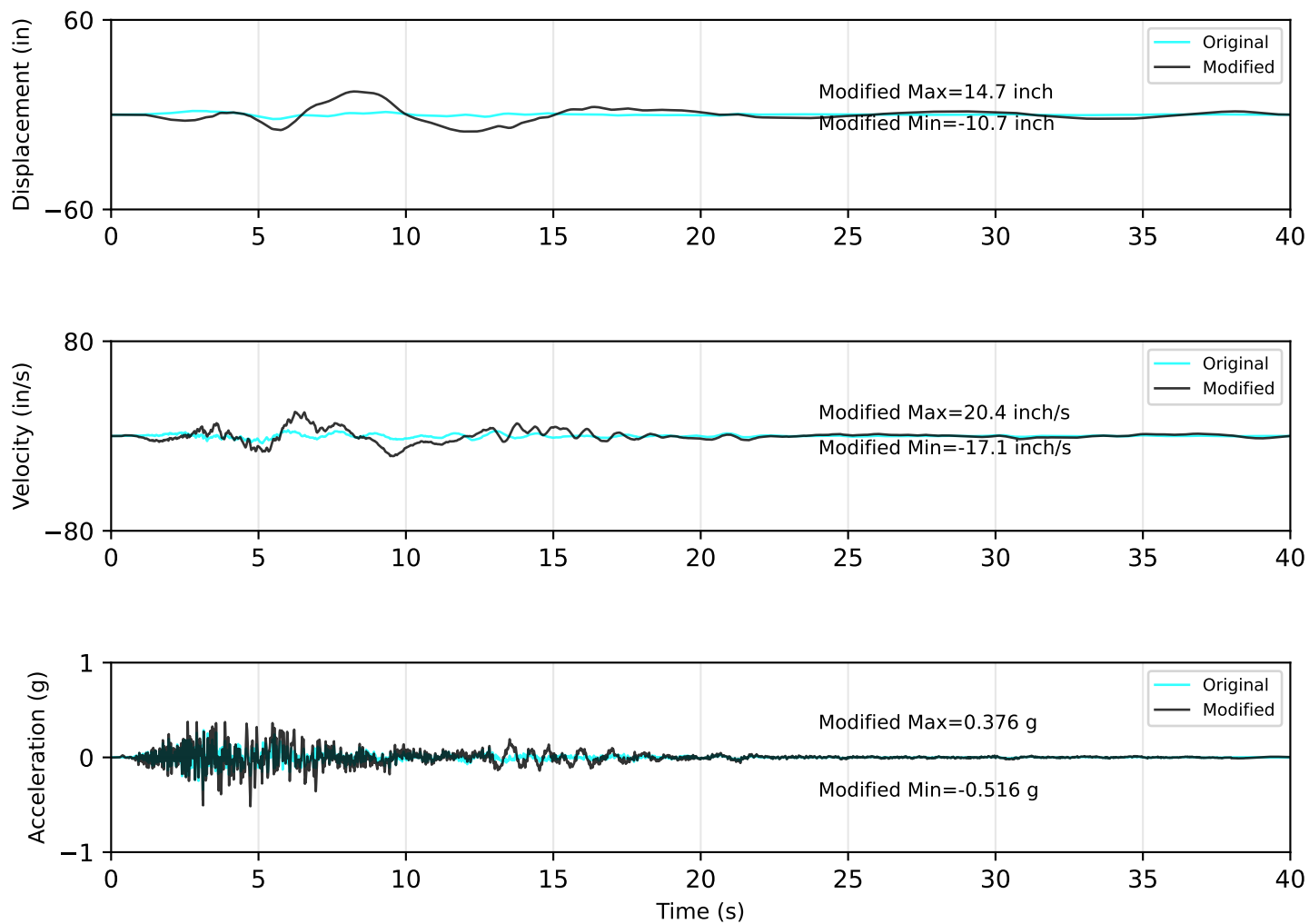


Figure E27. Unimproved Ground ASCE 7-22 DE Spectrum-matched Ground Motion - Set-2 Vertical

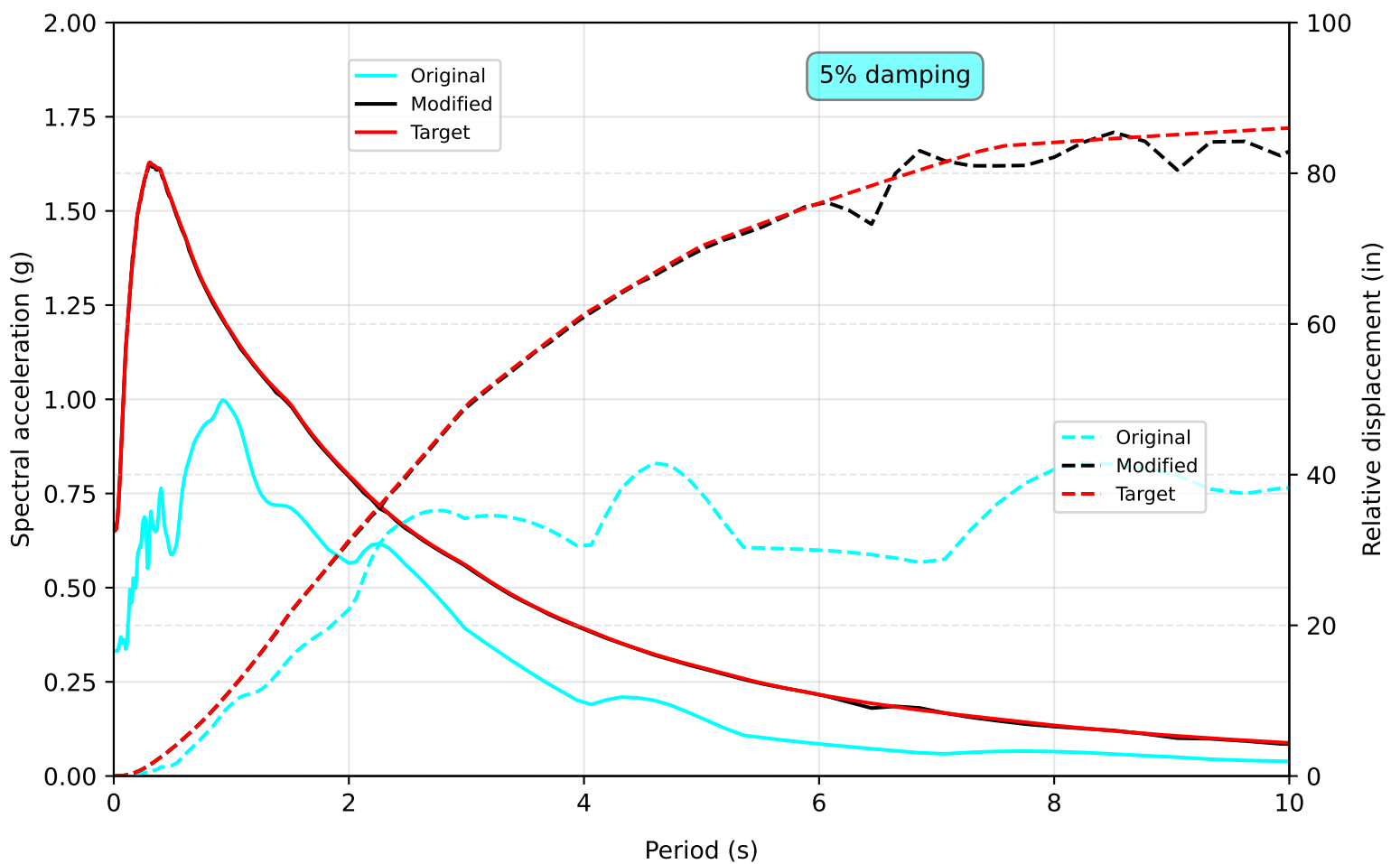
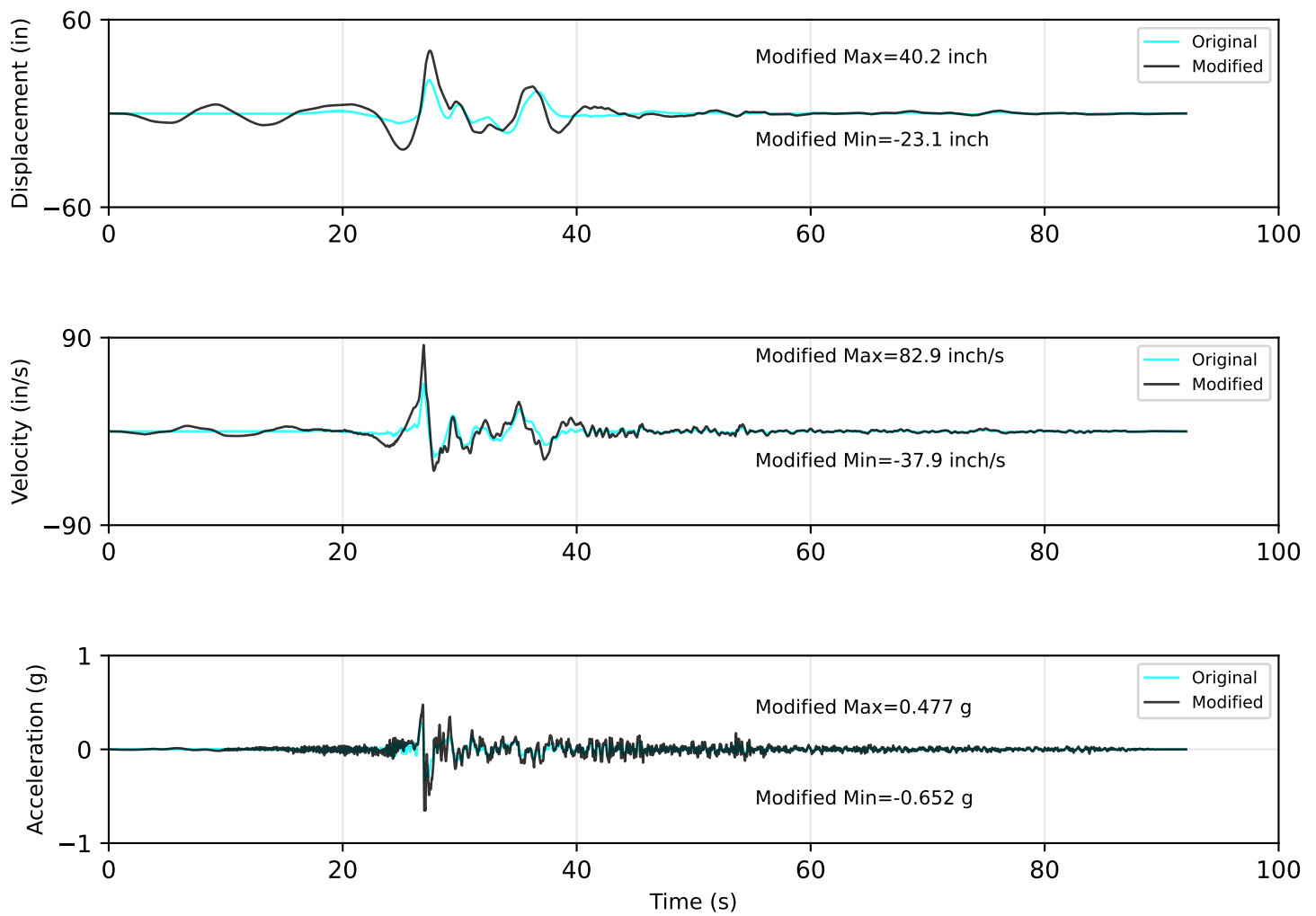


Figure E28. Unimproved Ground ASCE 7-22 DE Spectrum-matched Ground Motion - Set-3-Fault Normal

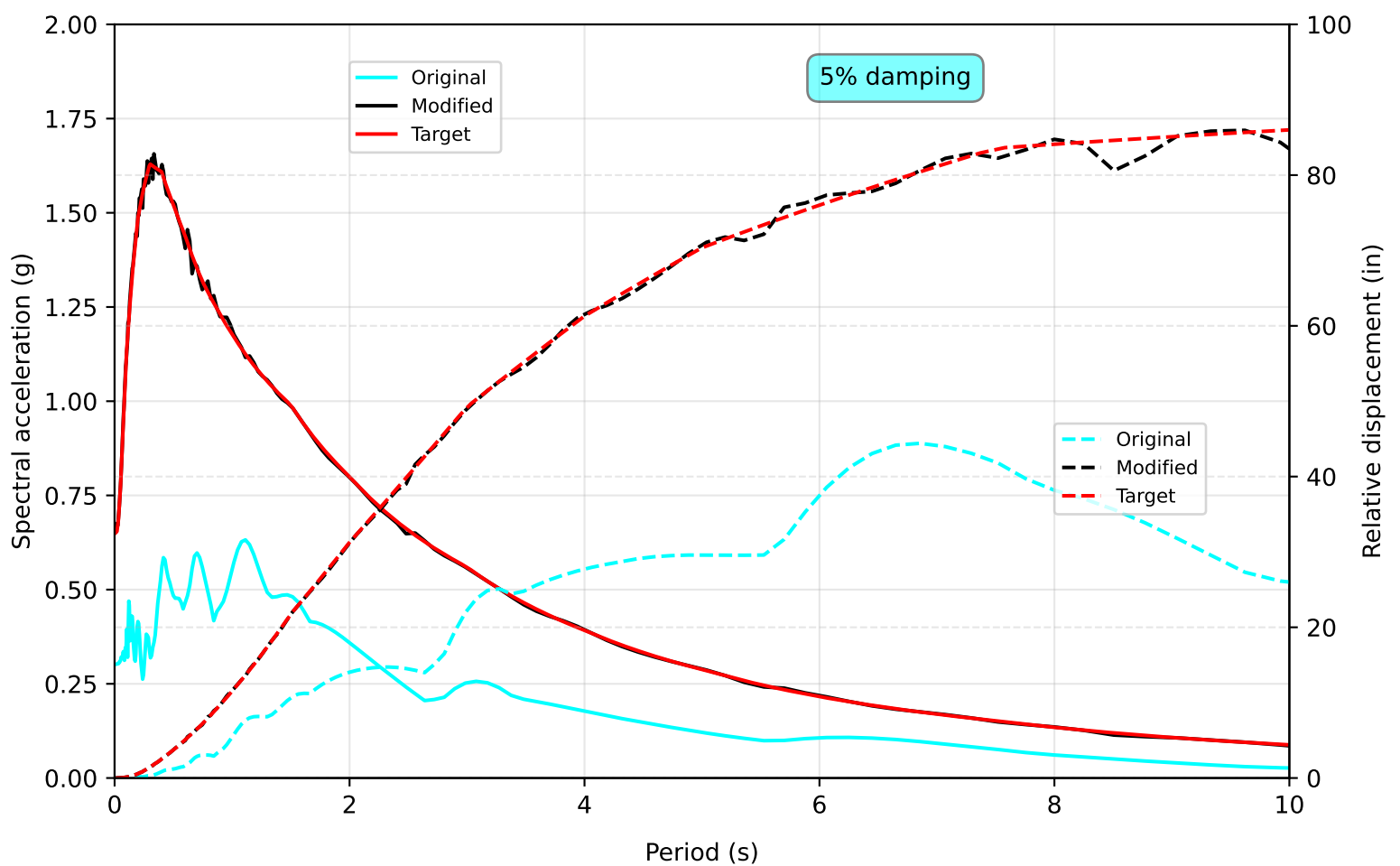
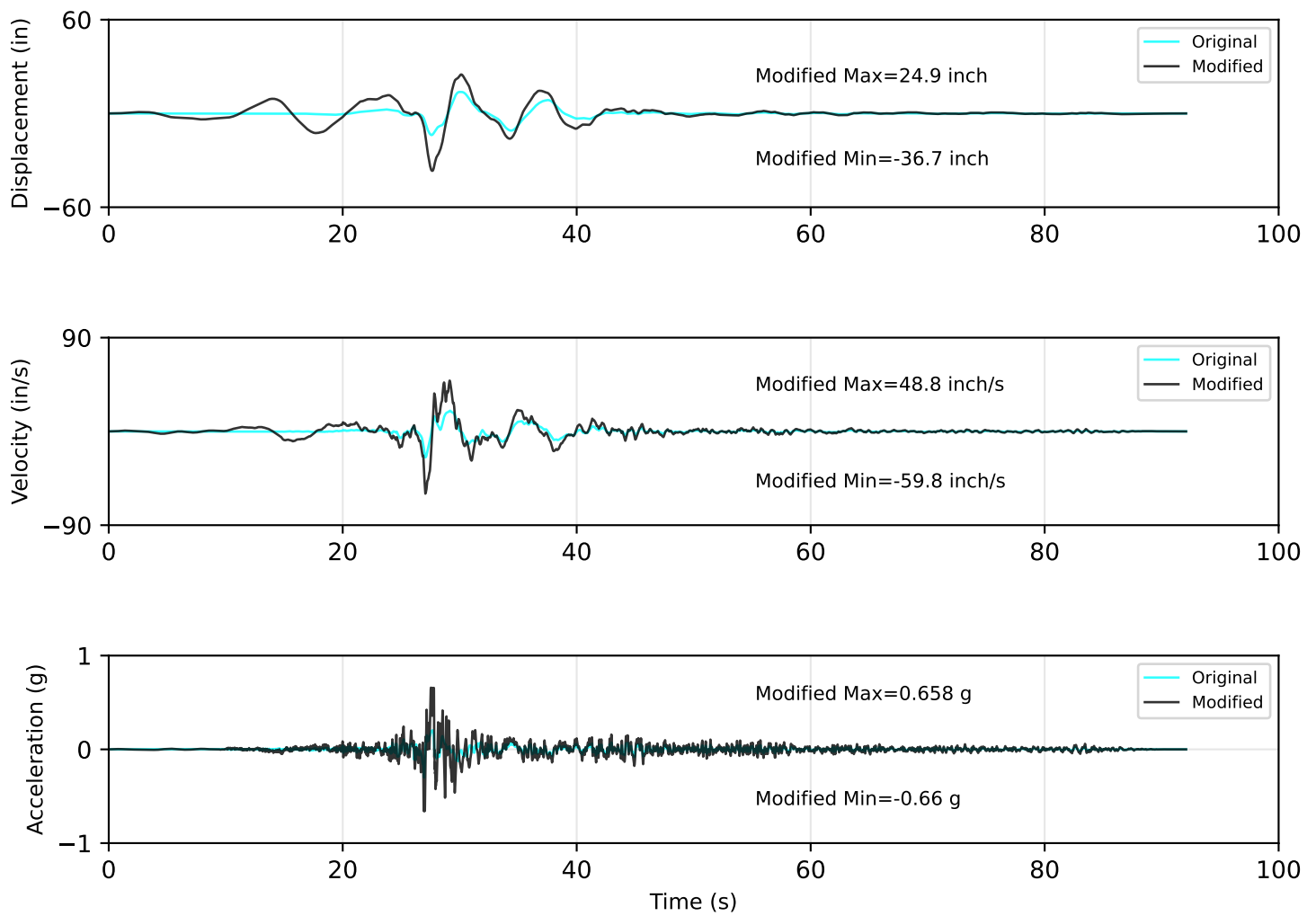


Figure E29. Unimproved Ground ASCE 7-22 DE Spectrum-matched Ground Motion - Set-3-Fault Parallel

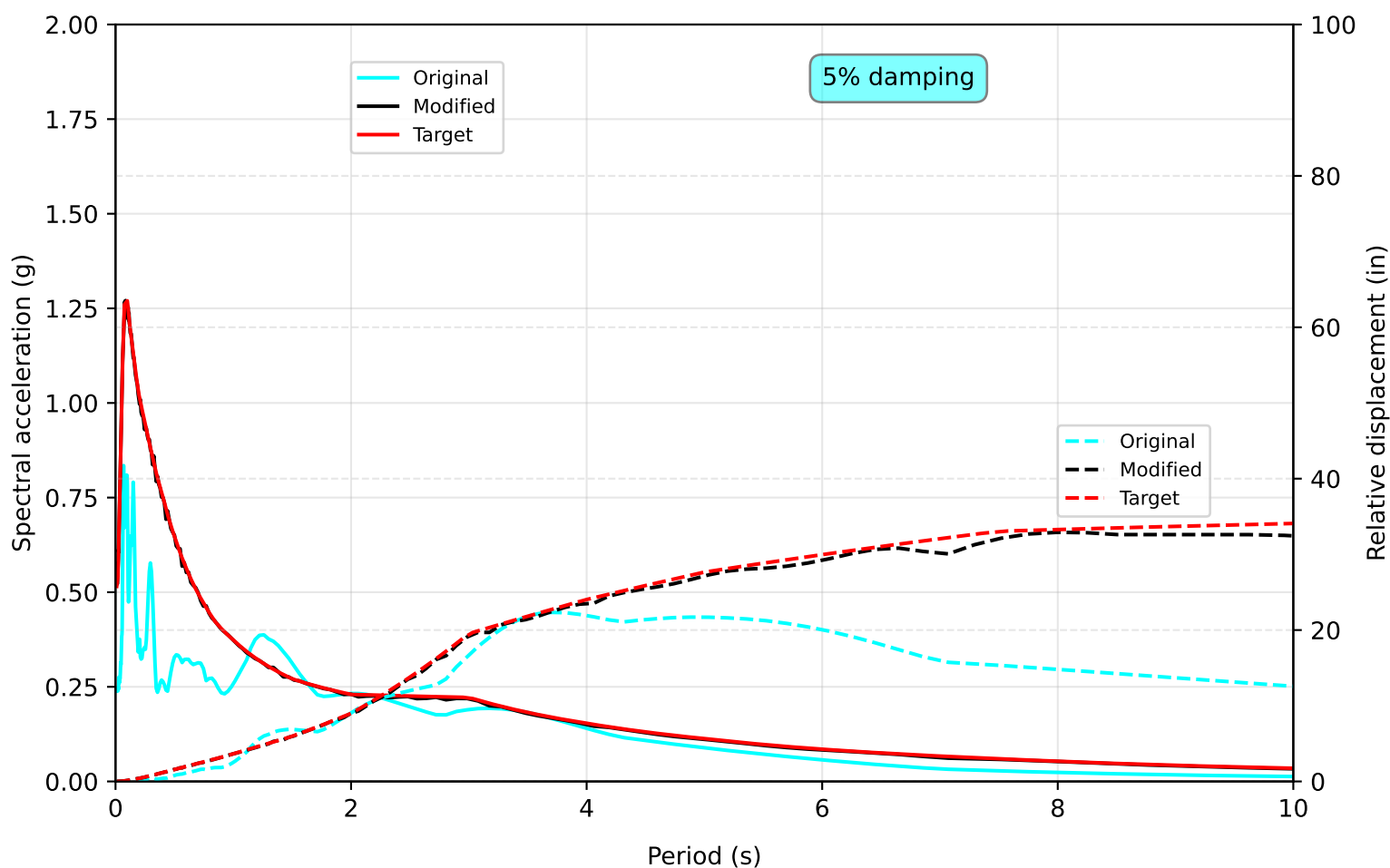
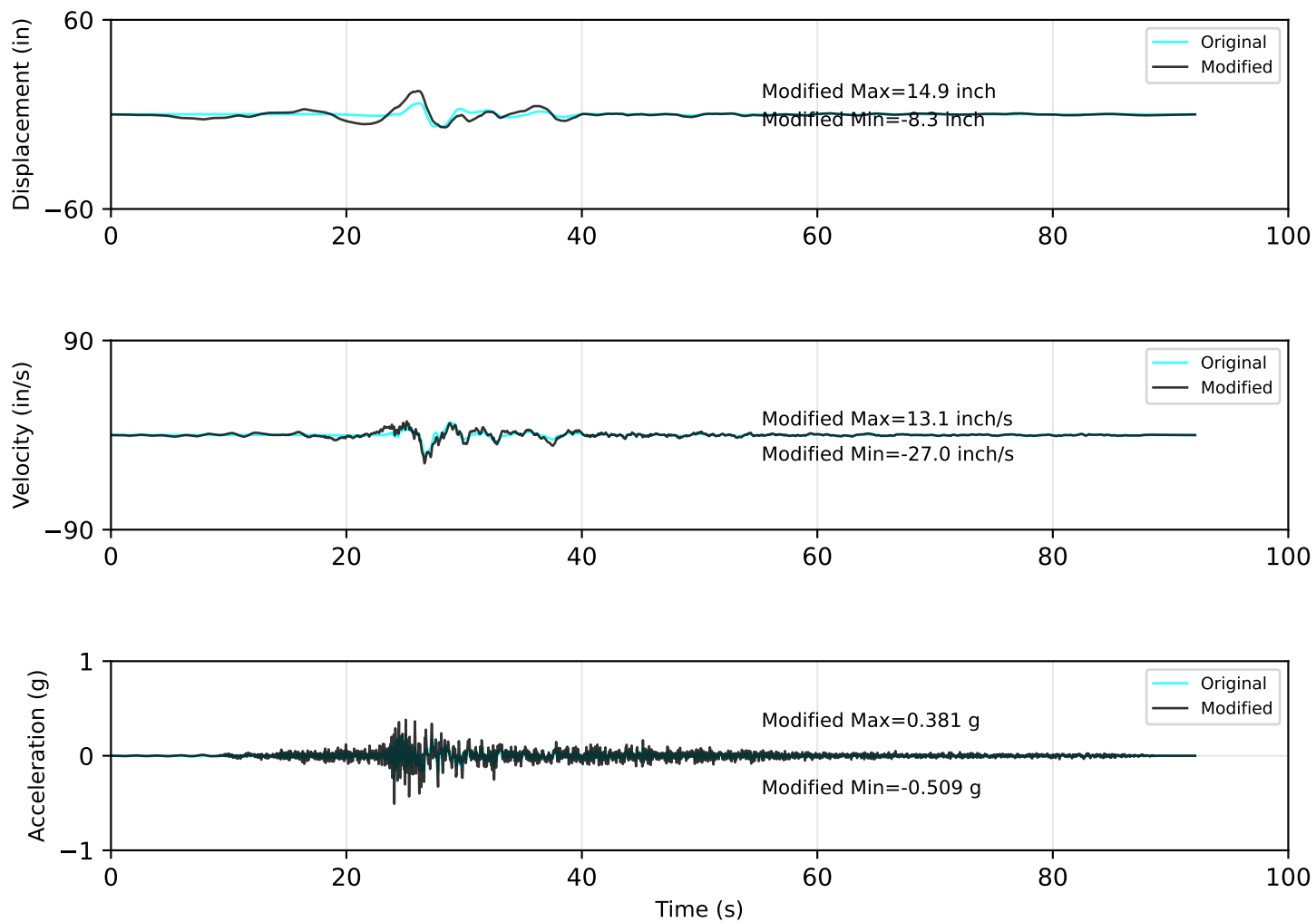


Figure E30. Unimproved Ground ASCE 7-22 DE Spectrum-matched Ground Motion - Set-3 Vertical

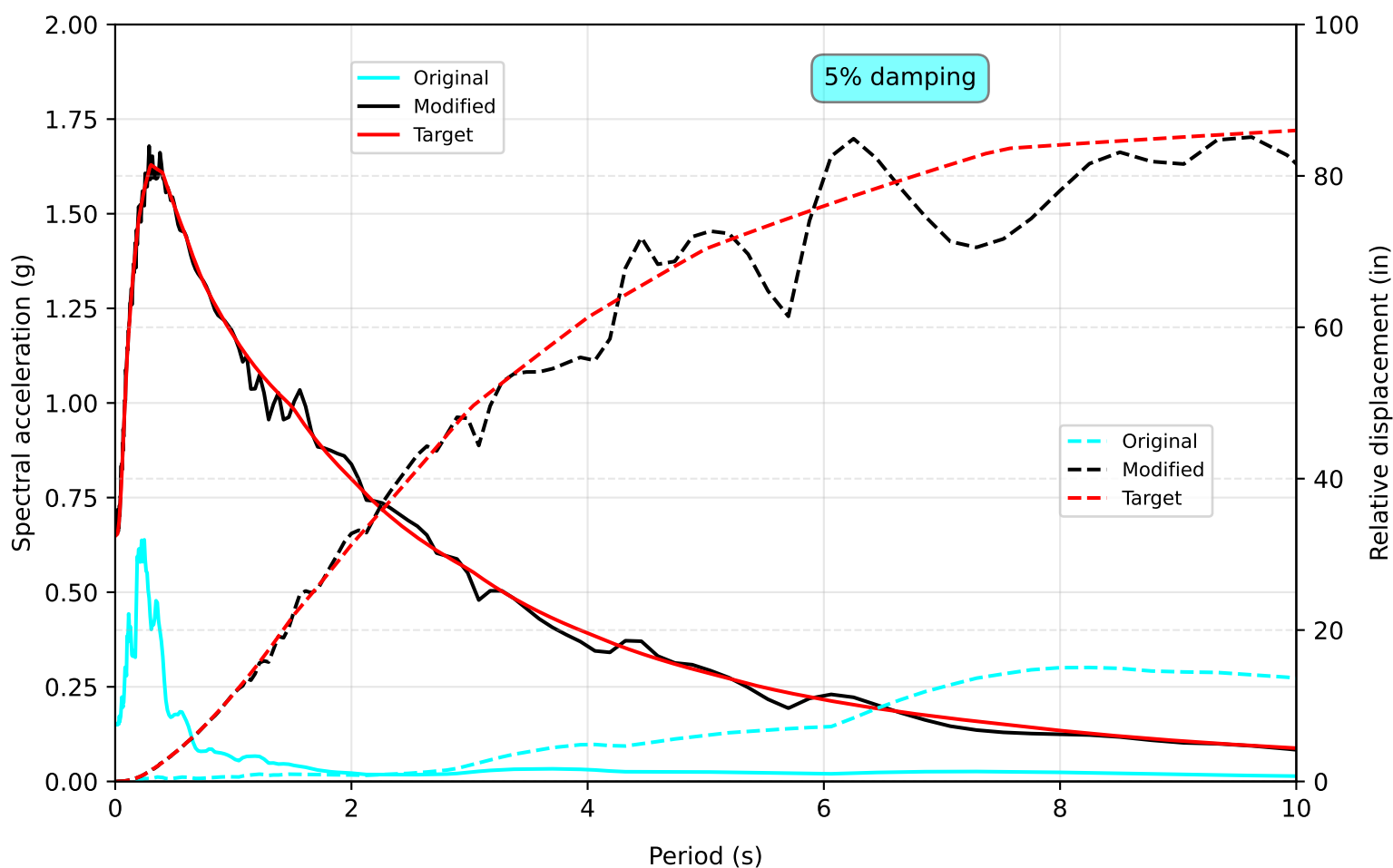
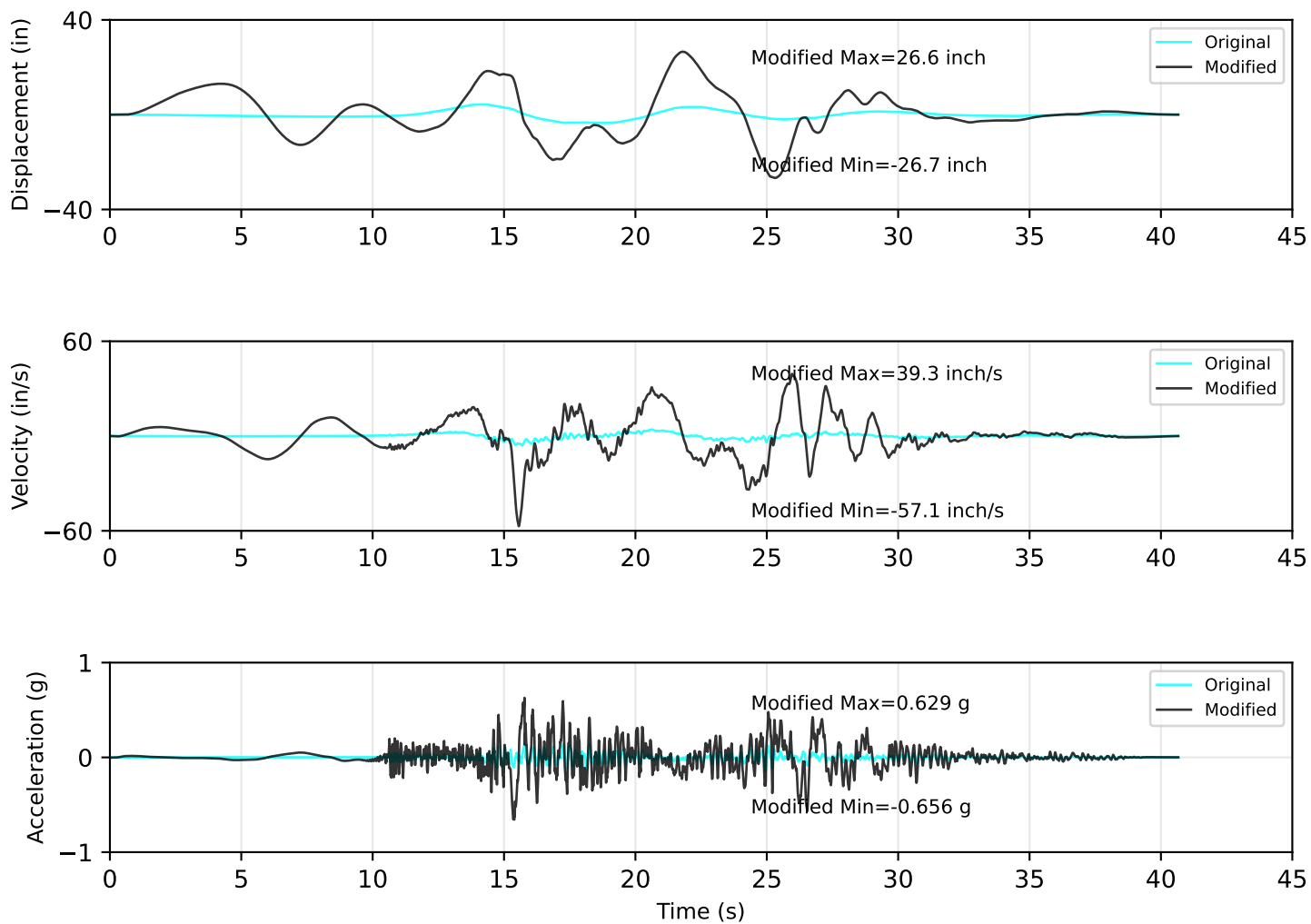


Figure E31. Unimproved Ground ASCE 7-22 DE Spectrum-matched Ground Motion - Set-4-Fault Normal

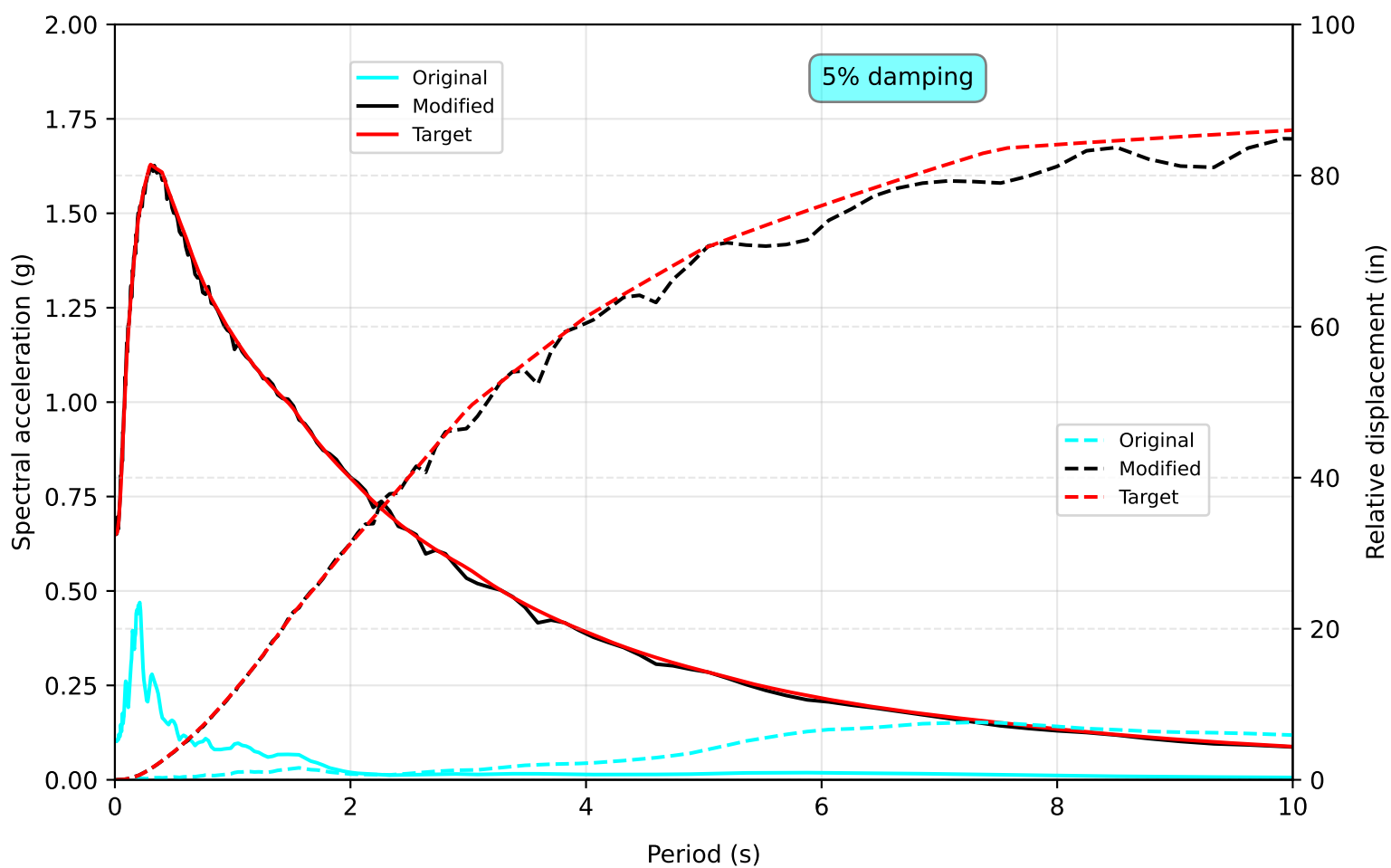
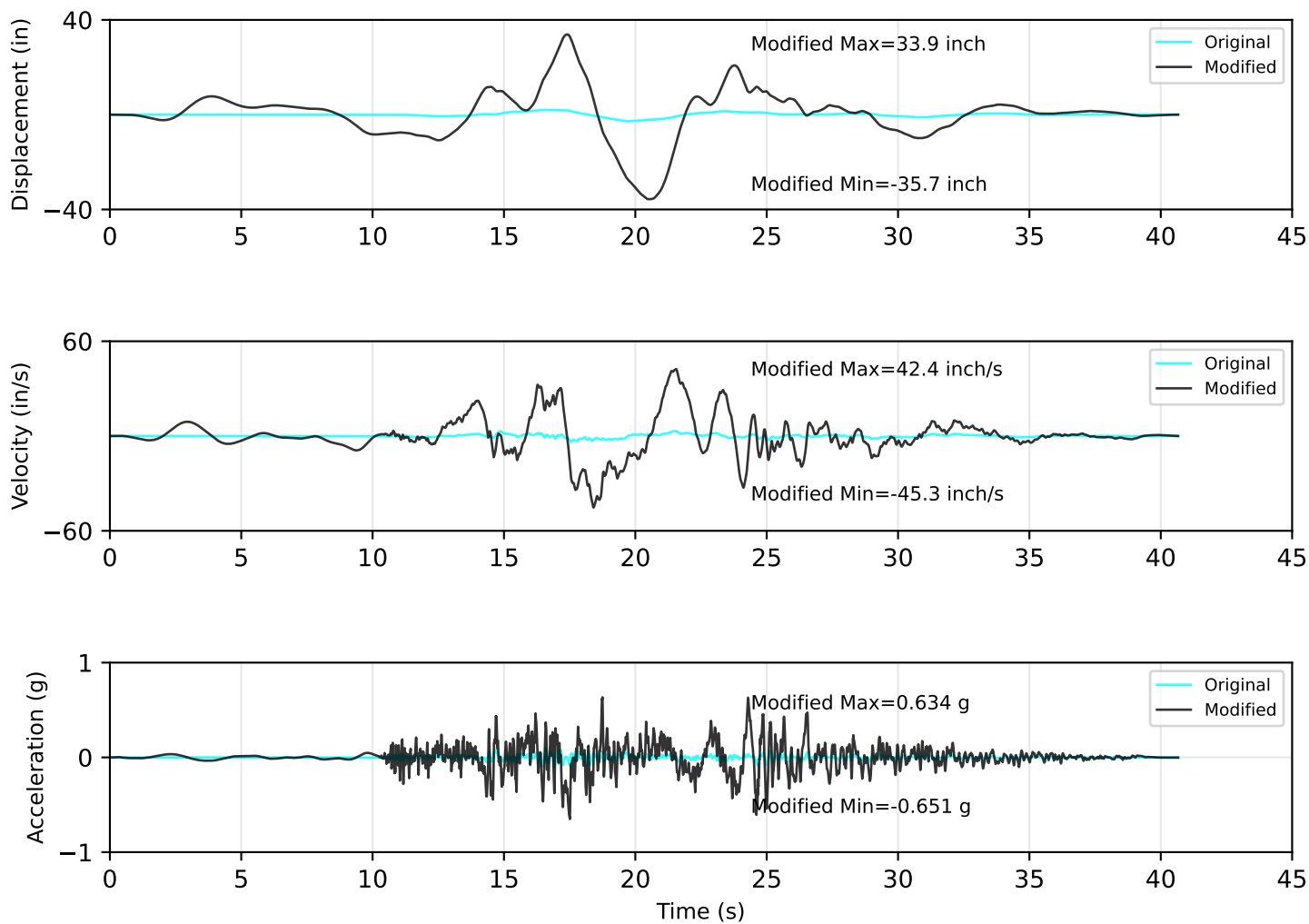


Figure E32. Unimproved Ground ASCE 7-22 DE Spectrum-matched Ground Motion - Set-4-Fault Parallel

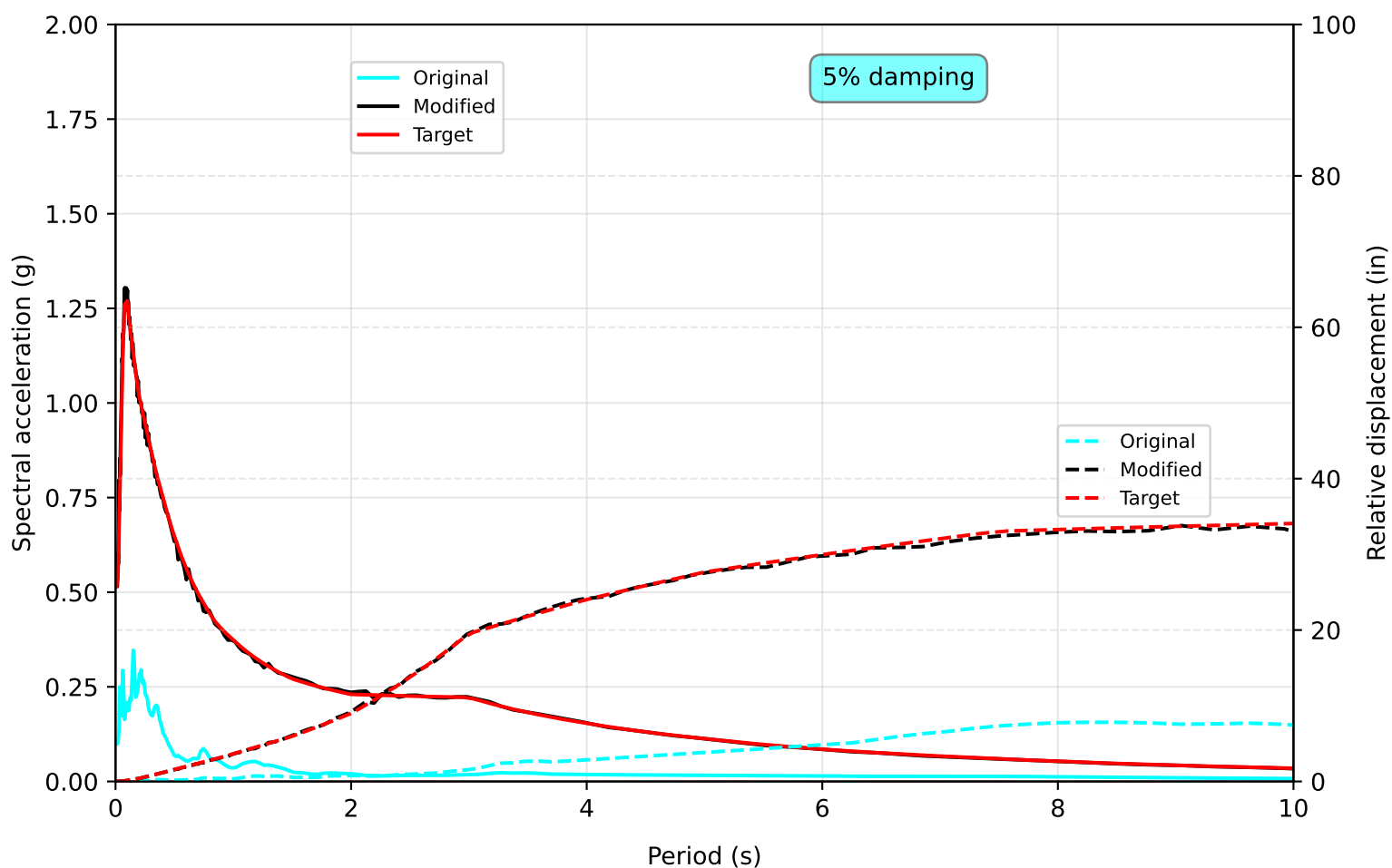
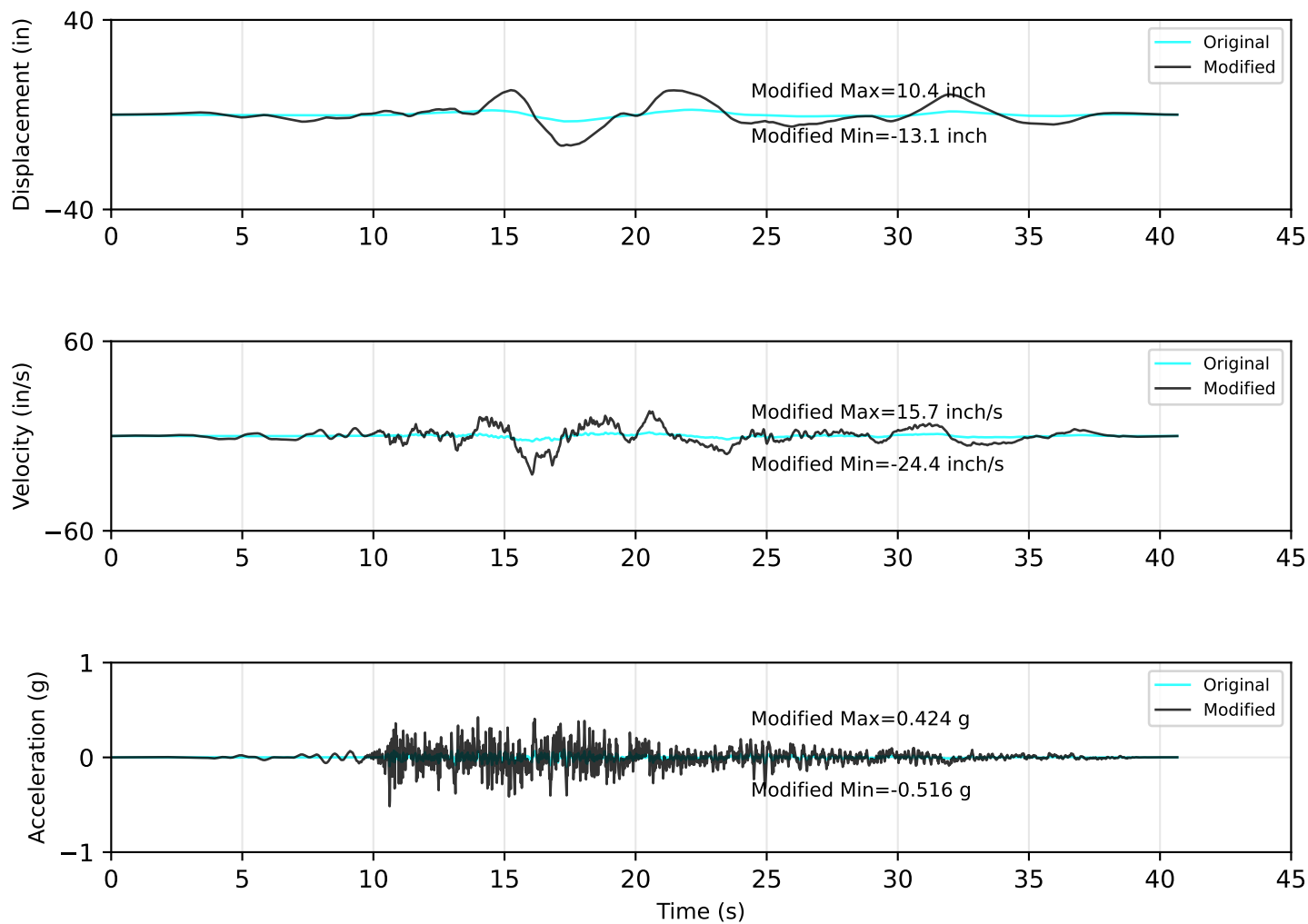


Figure E33. Unimproved Ground ASCE 7-22 DE Spectrum-matched Ground Motion - Set-4 Vertical

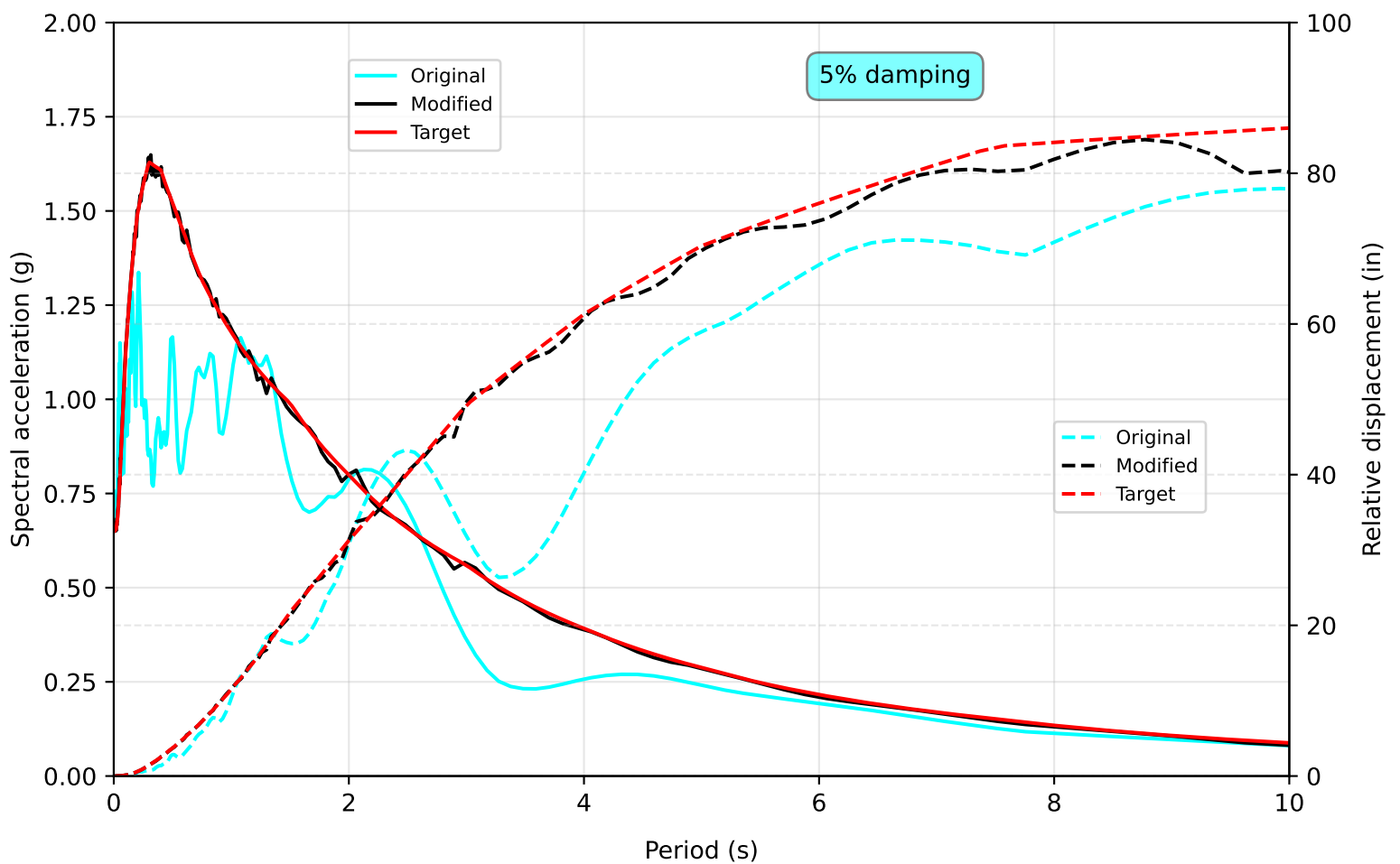
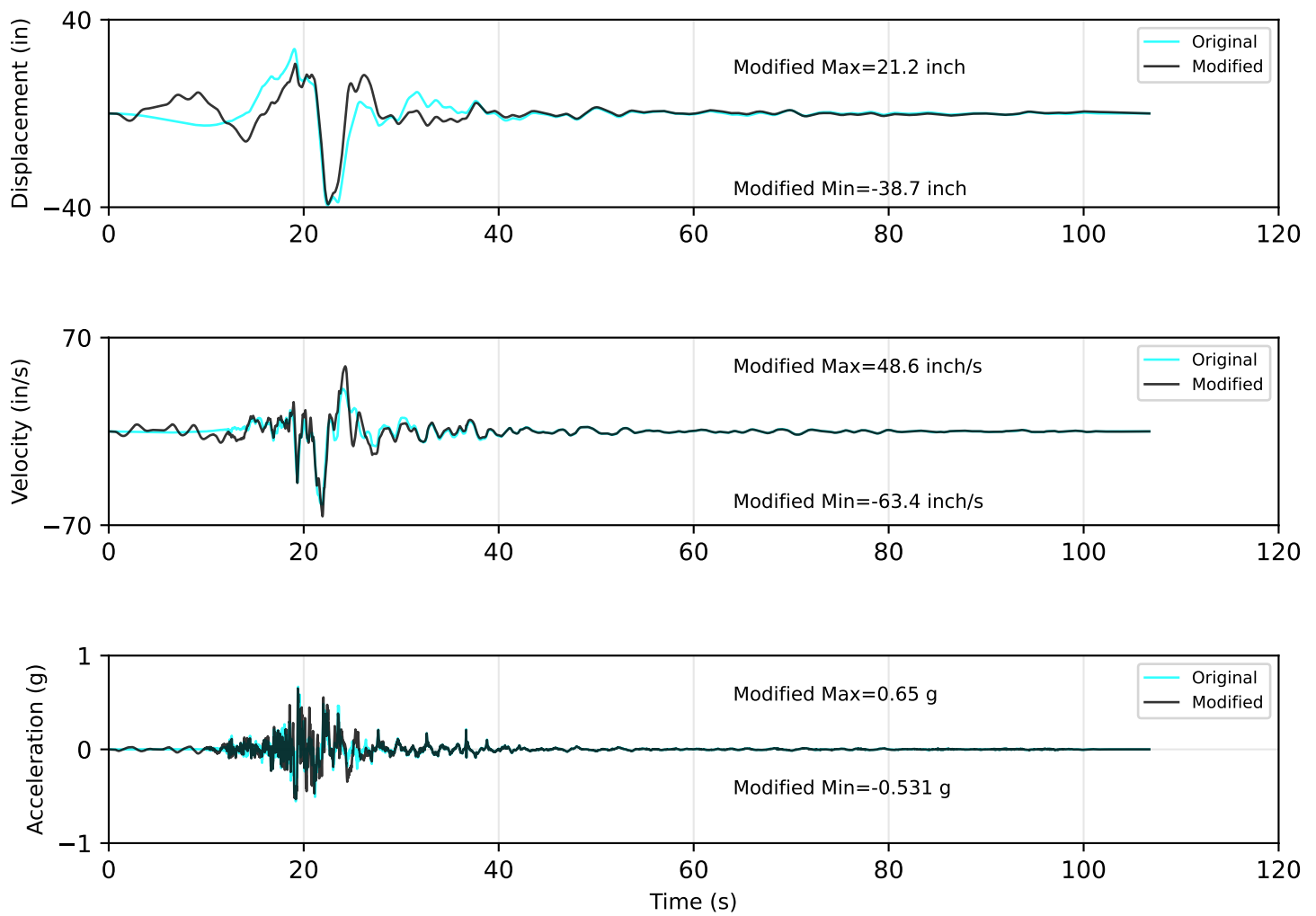


Figure E34. Unimproved Ground ASCE 7-22 DE Spectrum-matched Ground Motion - Set-5-Fault Normal

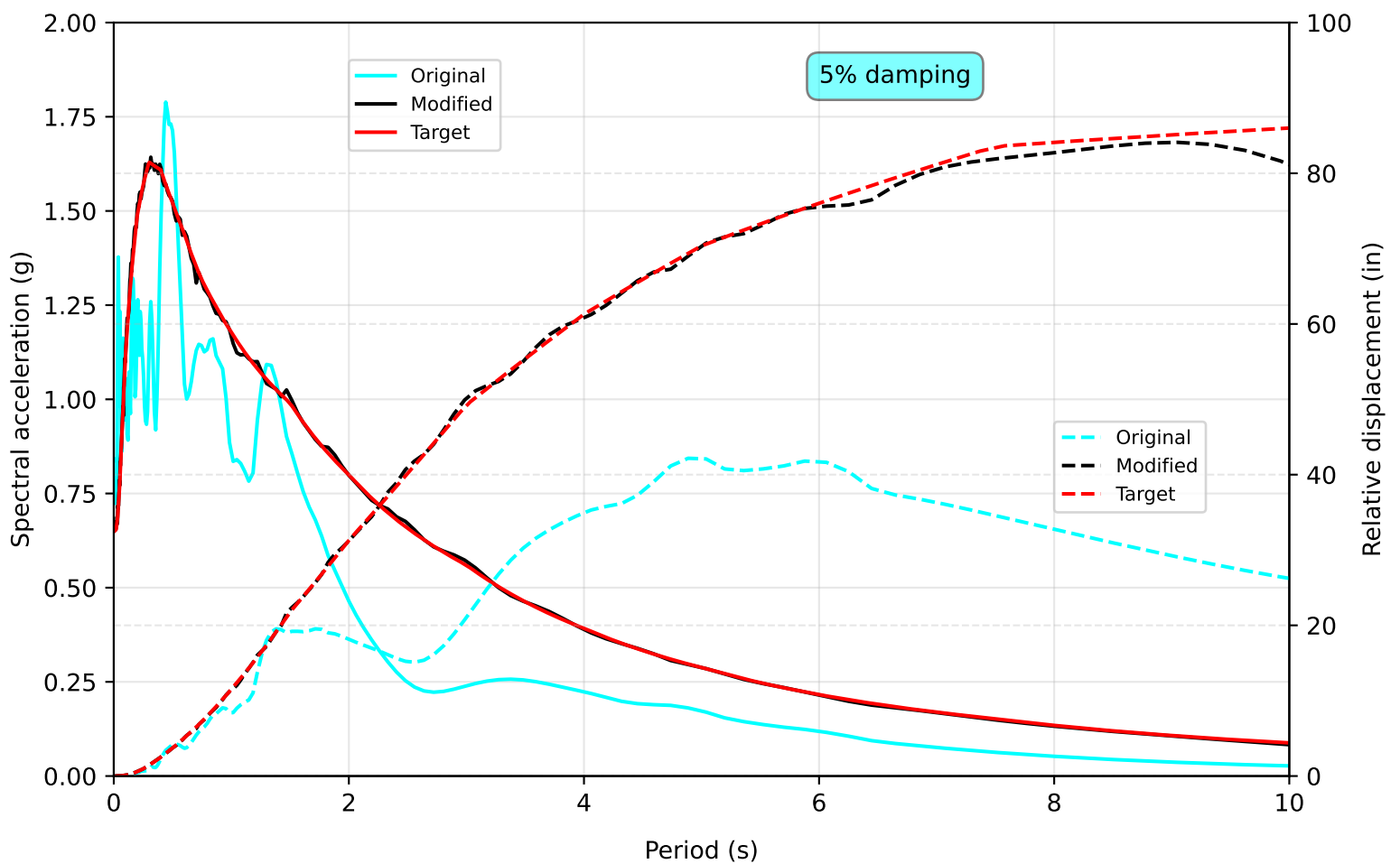
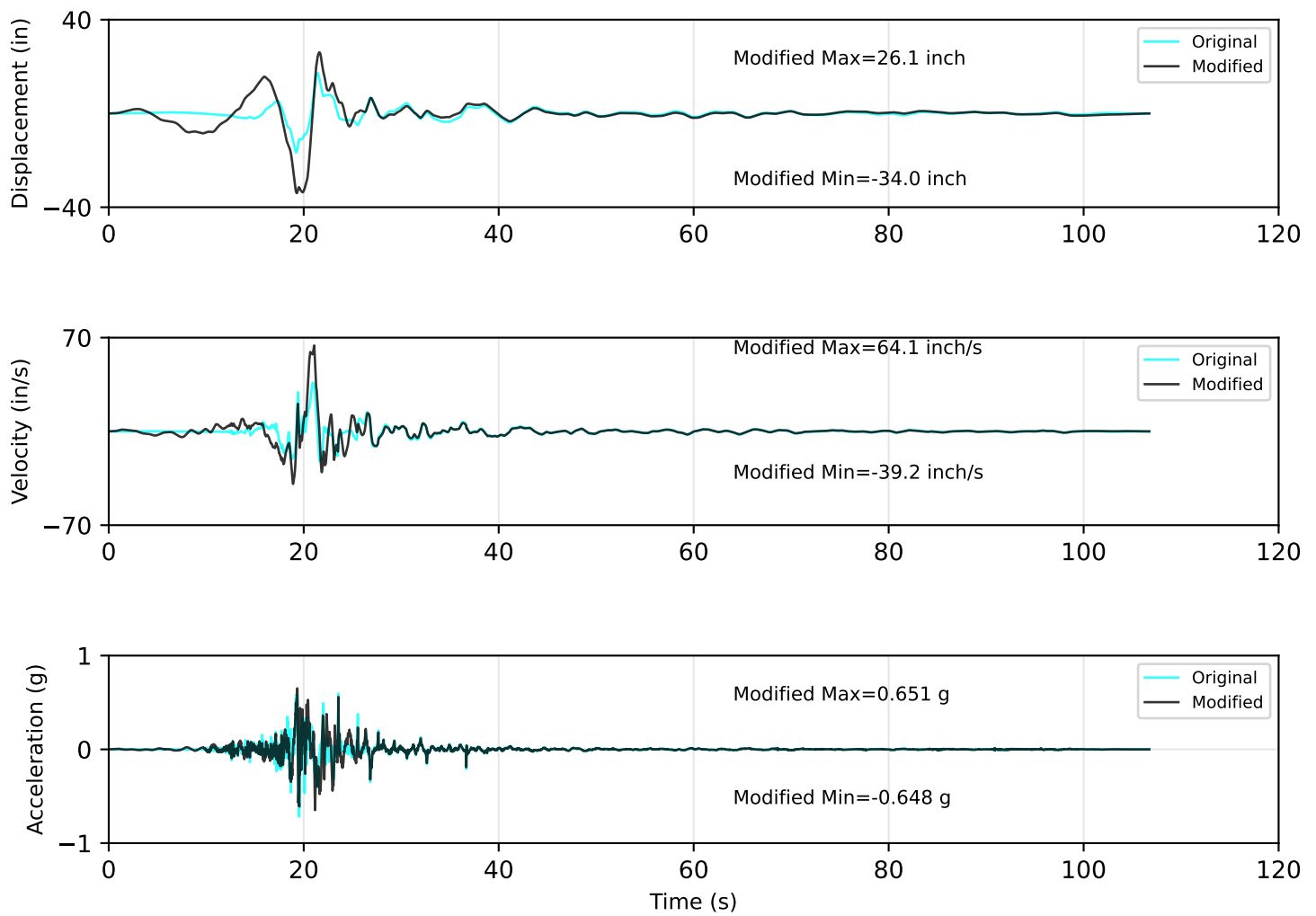


Figure E35. Unimproved Ground ASCE 7-22 DE Spectrum-matched Ground Motion - Set-5-Fault Parallel

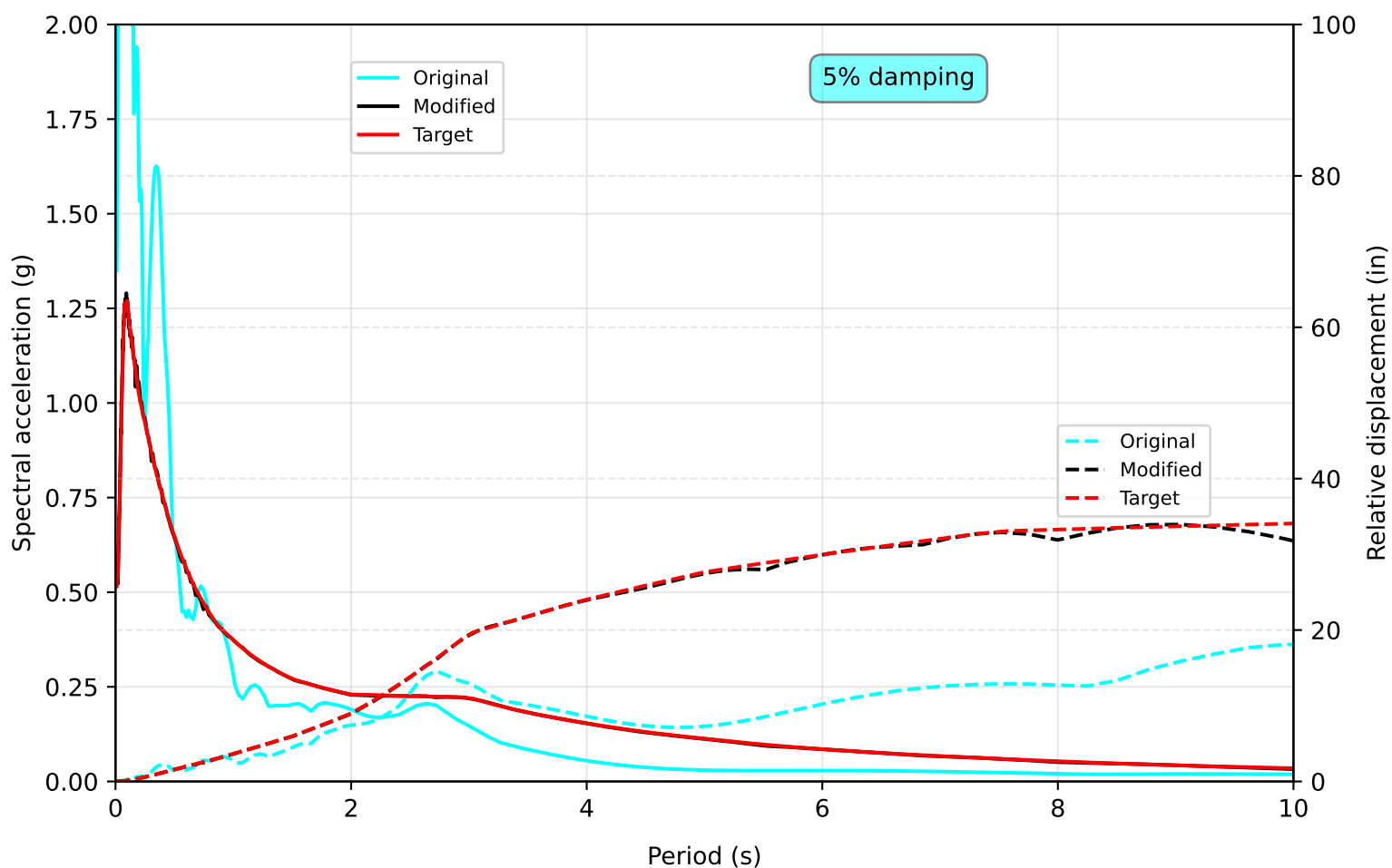
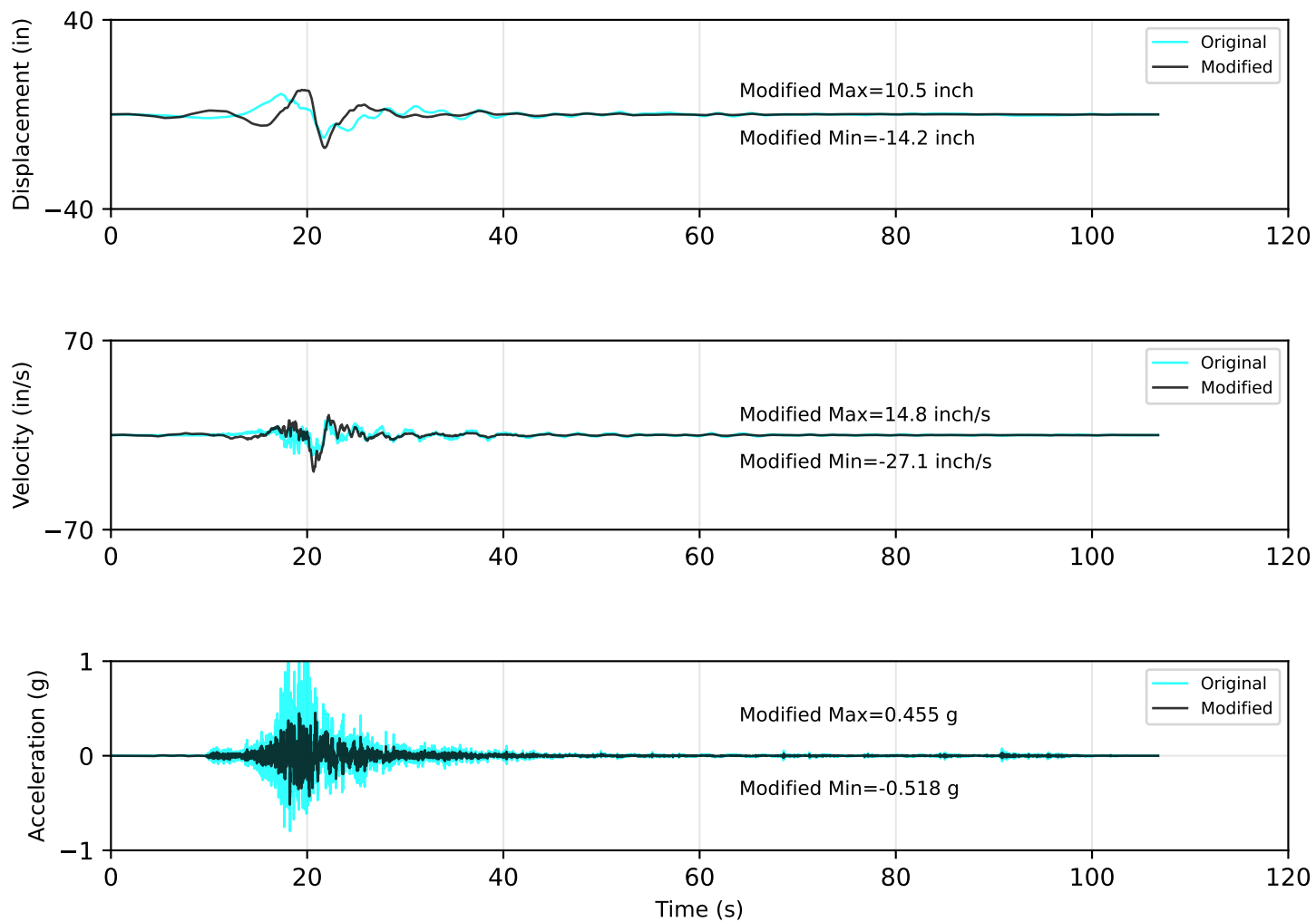


Figure E36. Unimproved Ground ASCE 7-22 DE Spectrum-matched Ground Motion - Set-5 Vertical

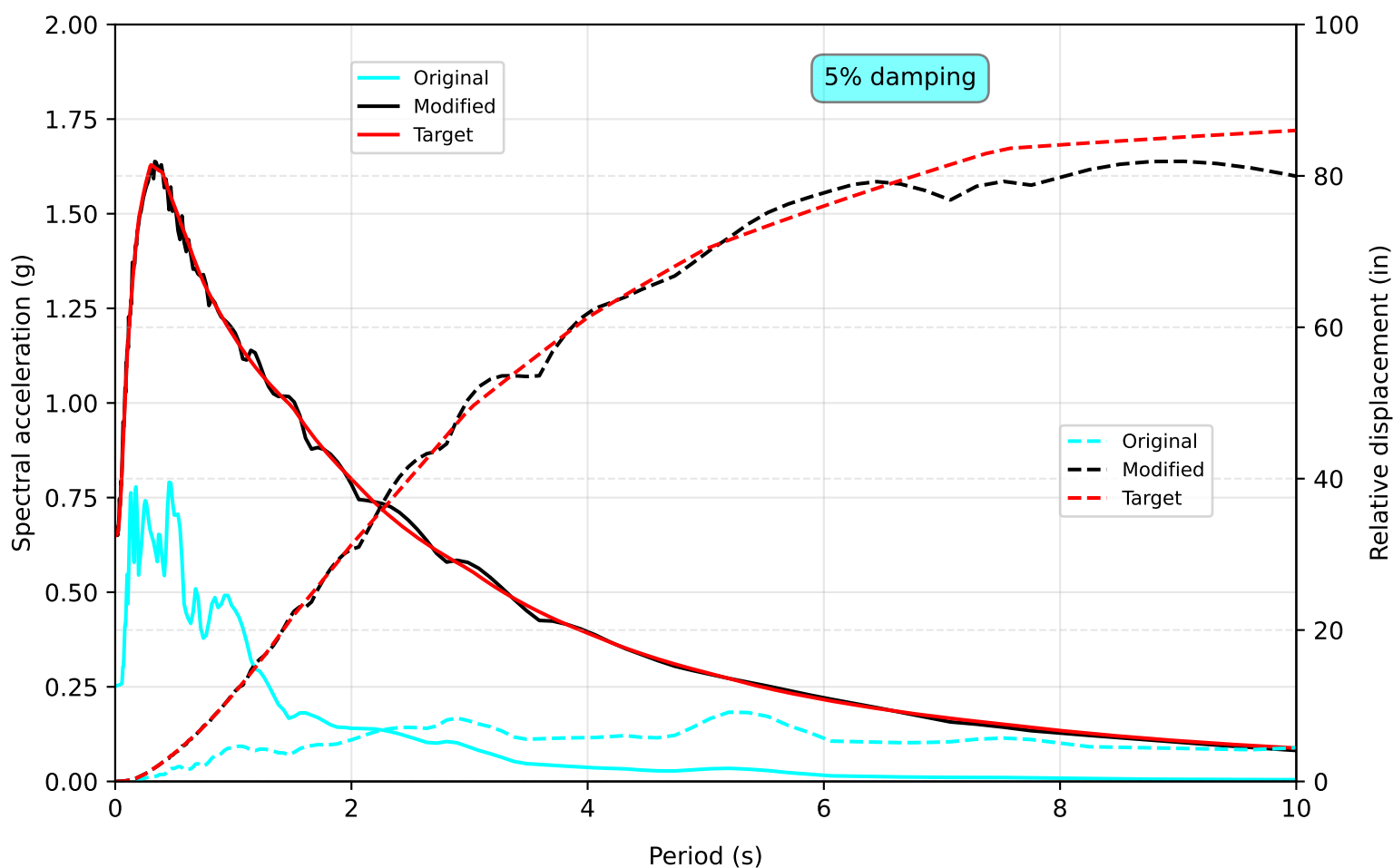
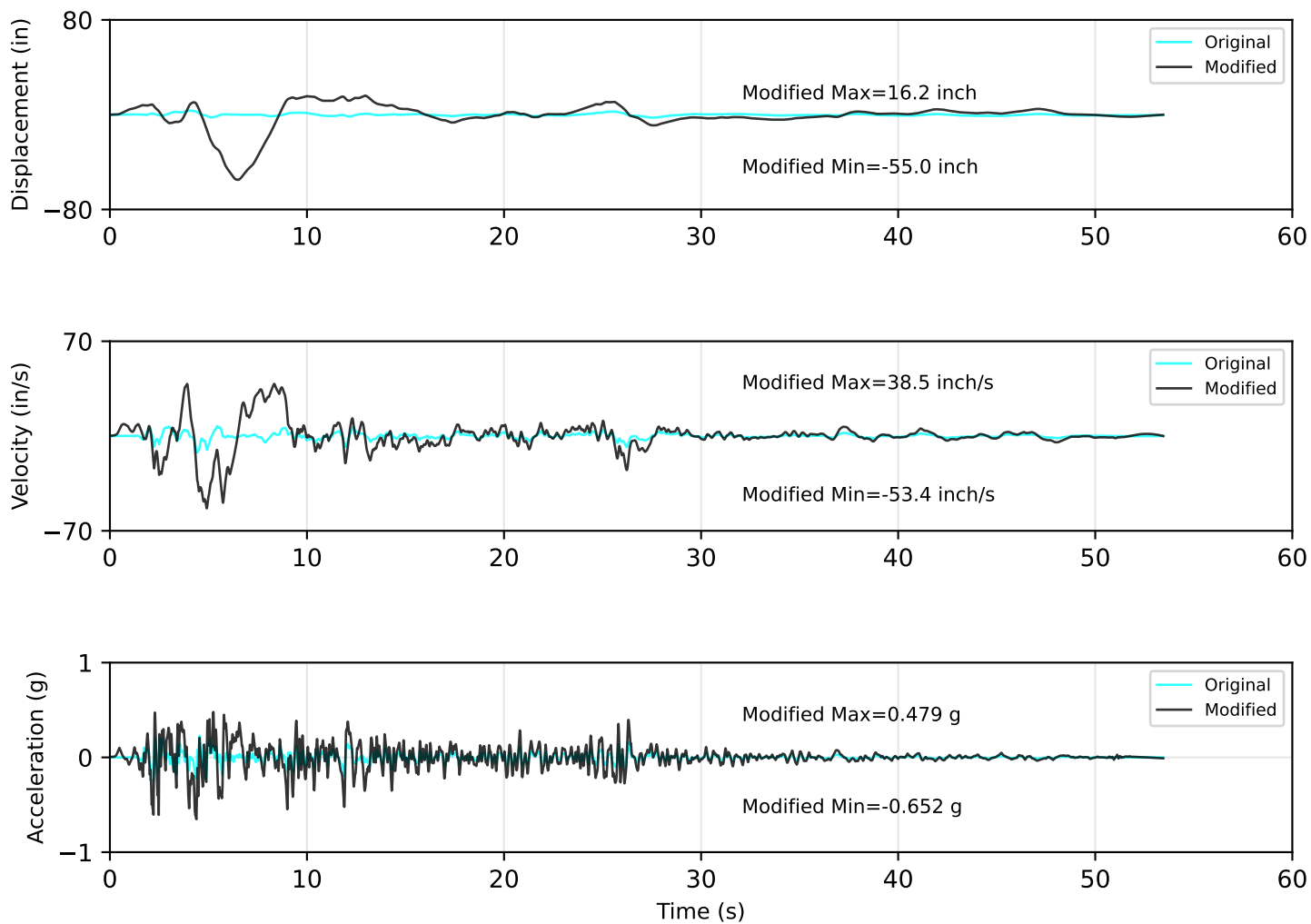


Figure E37. Unimproved Ground ASCE 7-22 DE Spectrum-matched Ground Motion - Set-6-Fault Normal

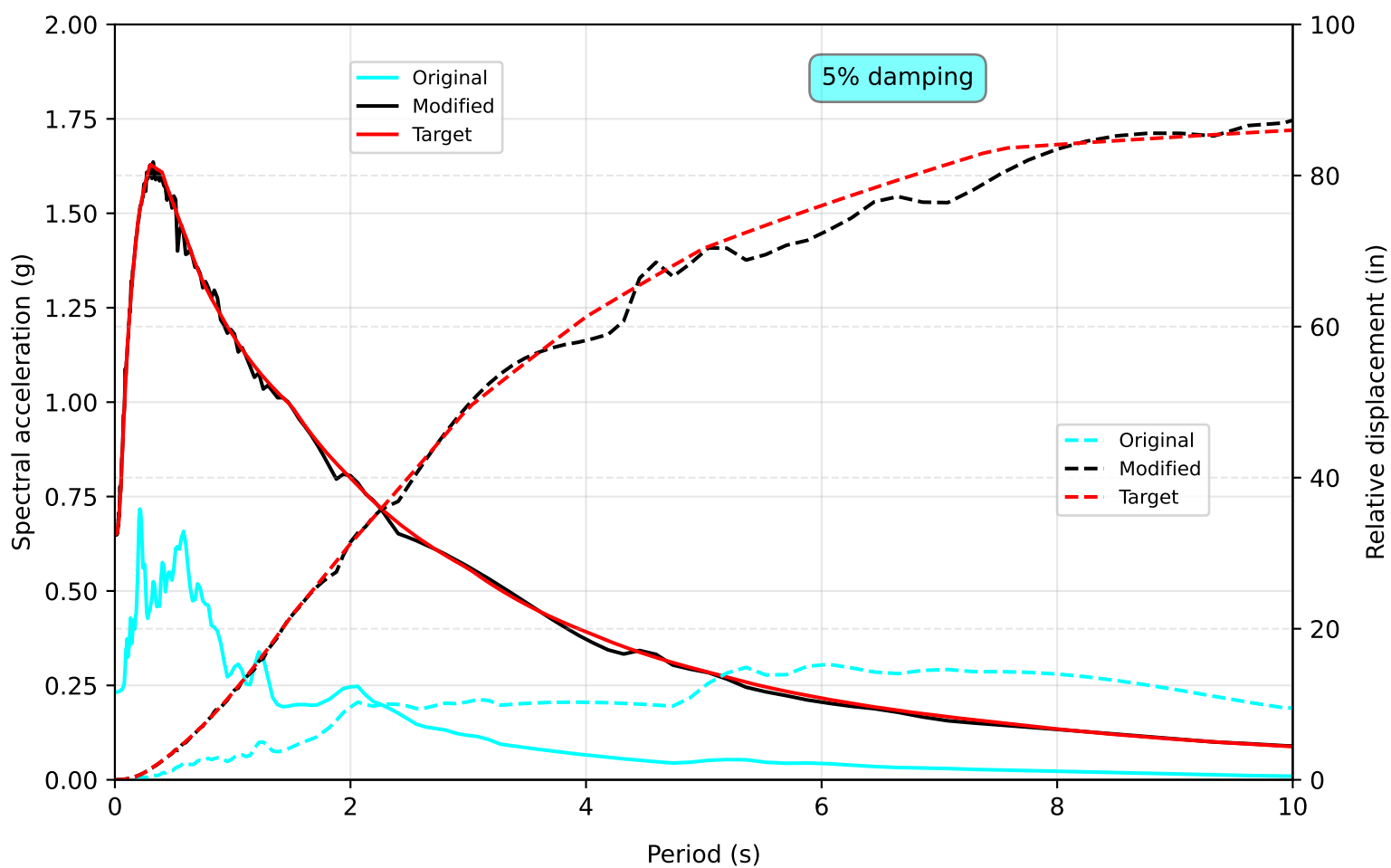
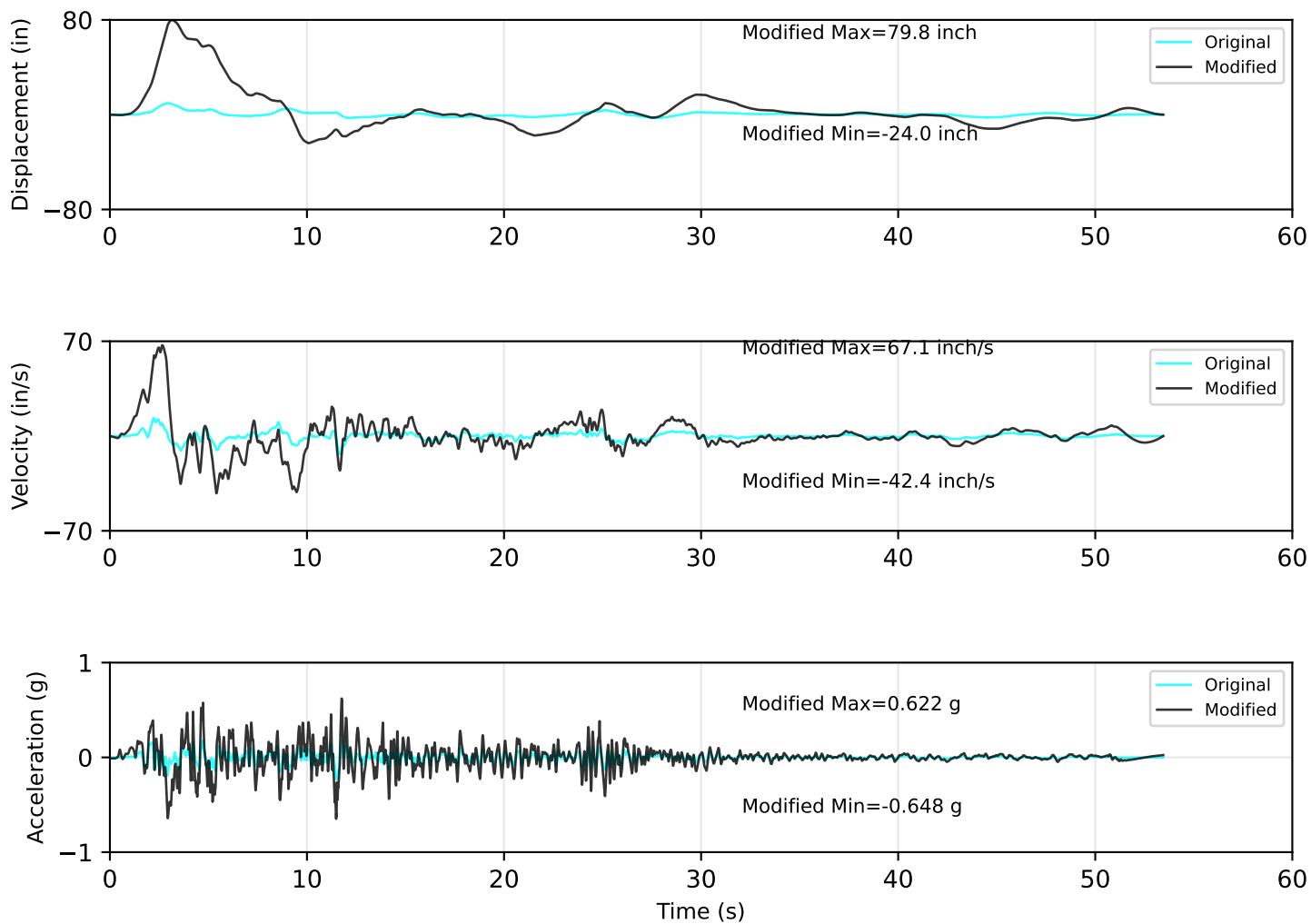


Figure E38. Unimproved Ground ASCE 7-22 DE Spectrum-matched Ground Motion - Set-6-Fault Parallel

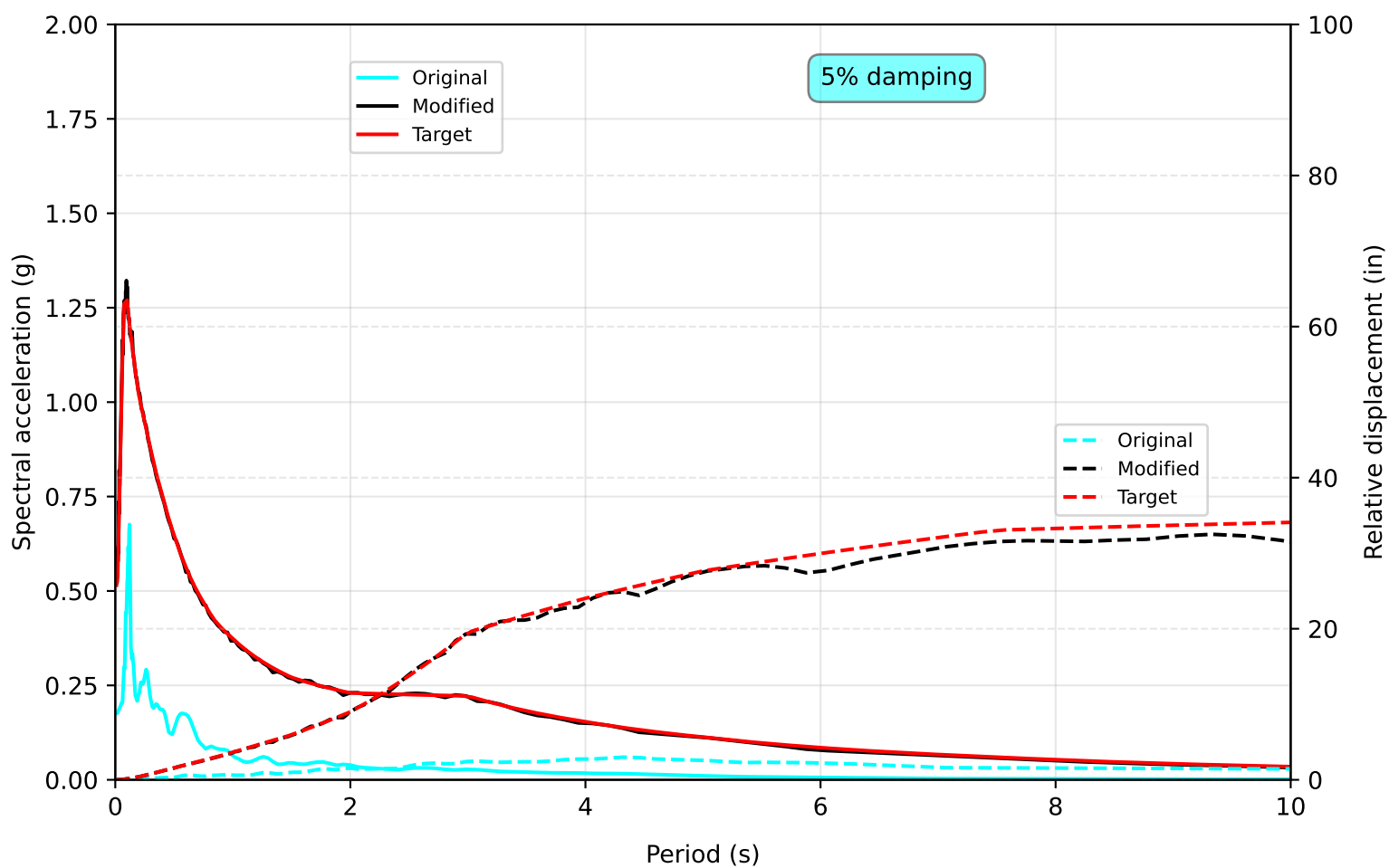
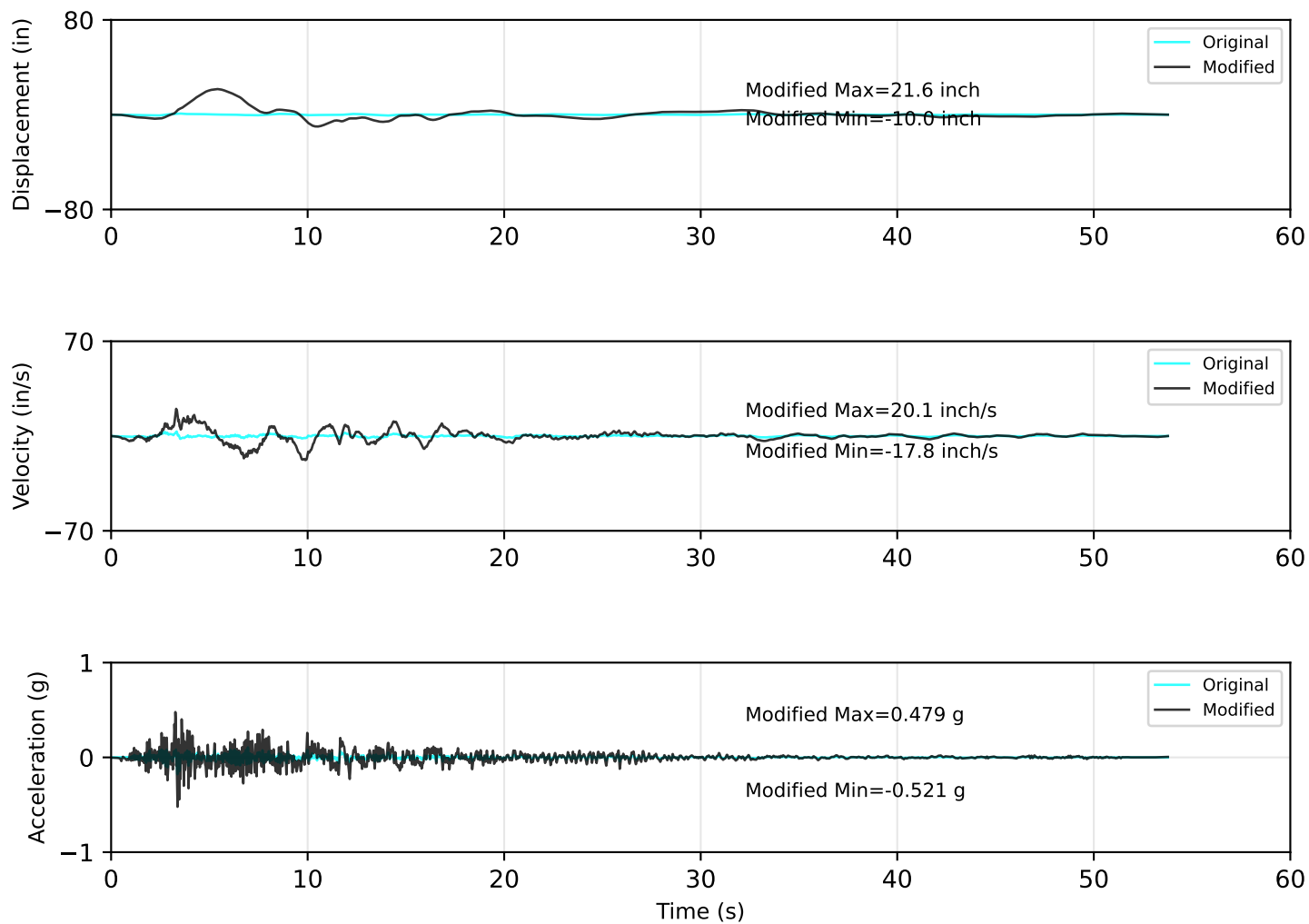


Figure E39. Unimproved Ground ASCE 7-22 DE Spectrum-matched Ground Motion - Set-6 Vertical

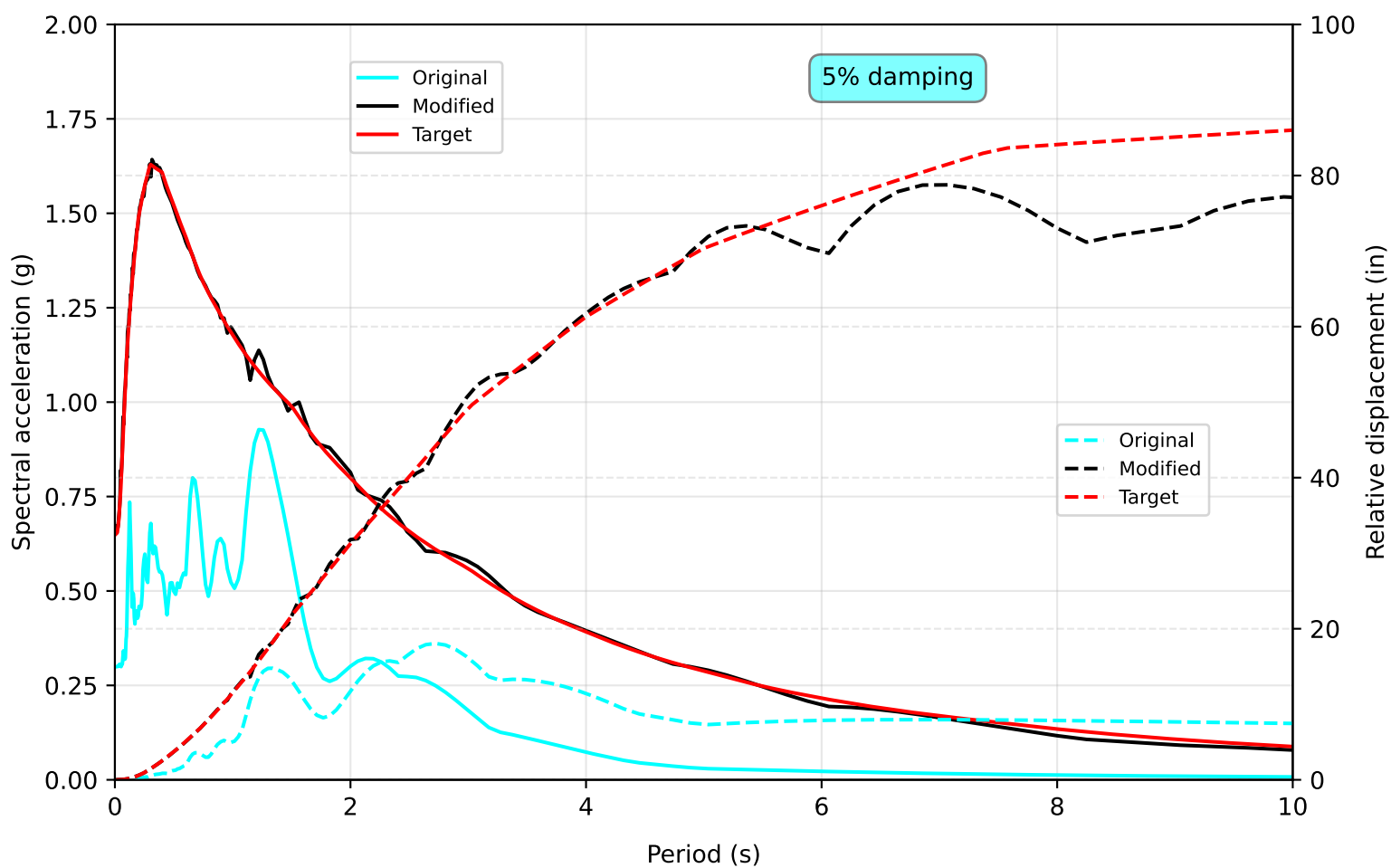
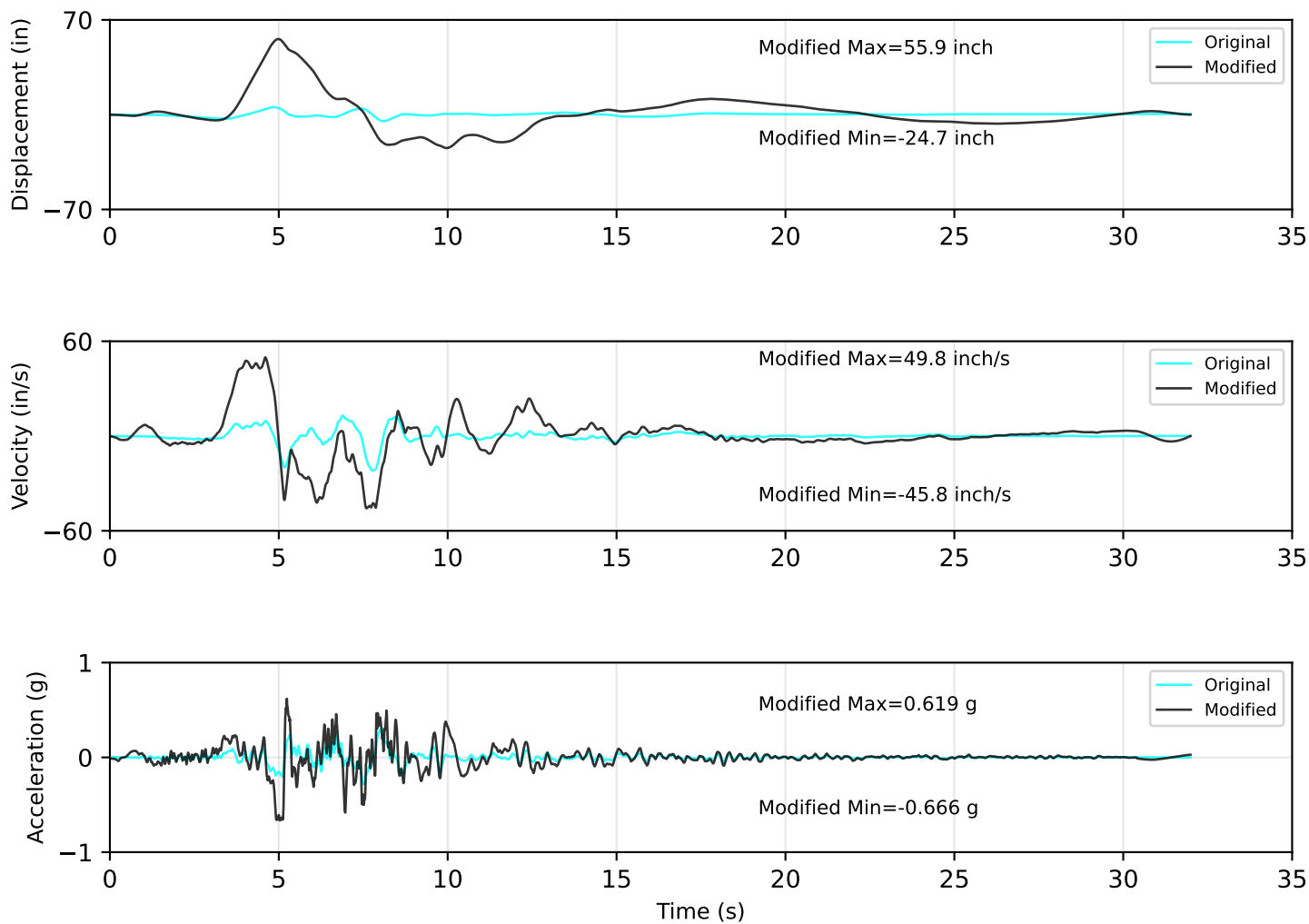


Figure E40. Unimproved Ground ASCE 7-22 DE Spectrum-matched Ground Motion - Set-7-Fault Normal

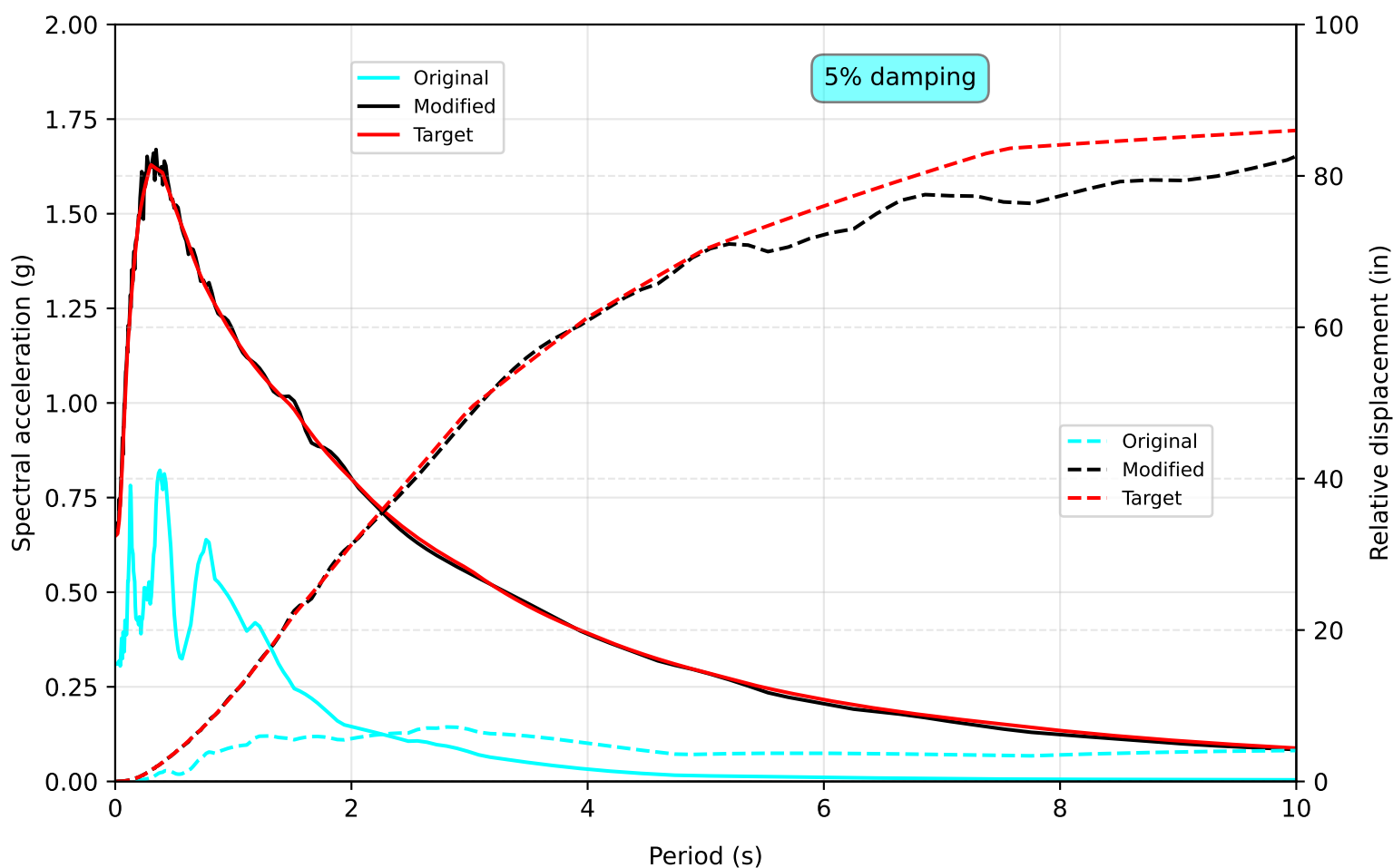
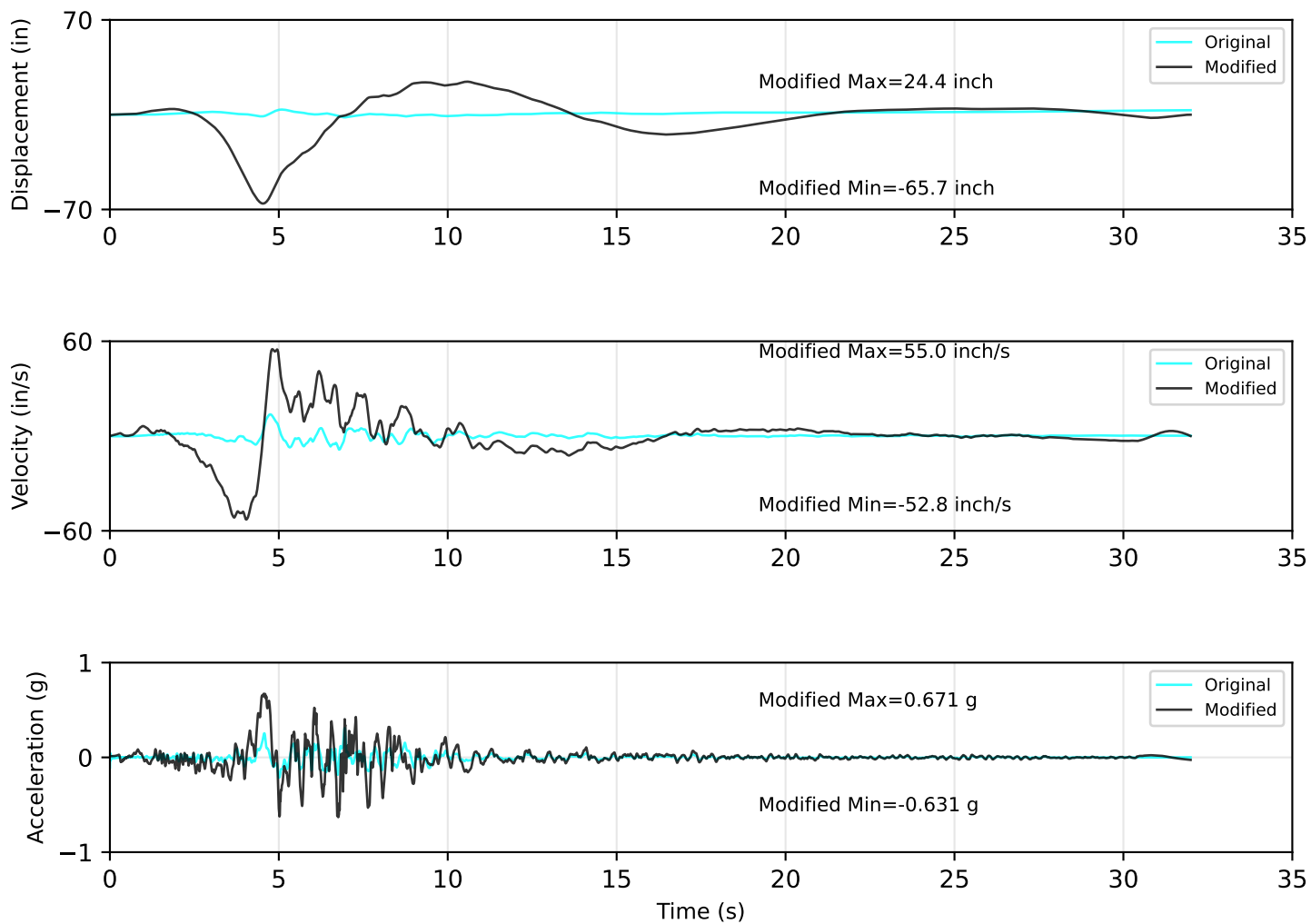


Figure E41. Unimproved Ground ASCE 7-22 DE Spectrum-matched Ground Motion - Set-7-Fault Parallel

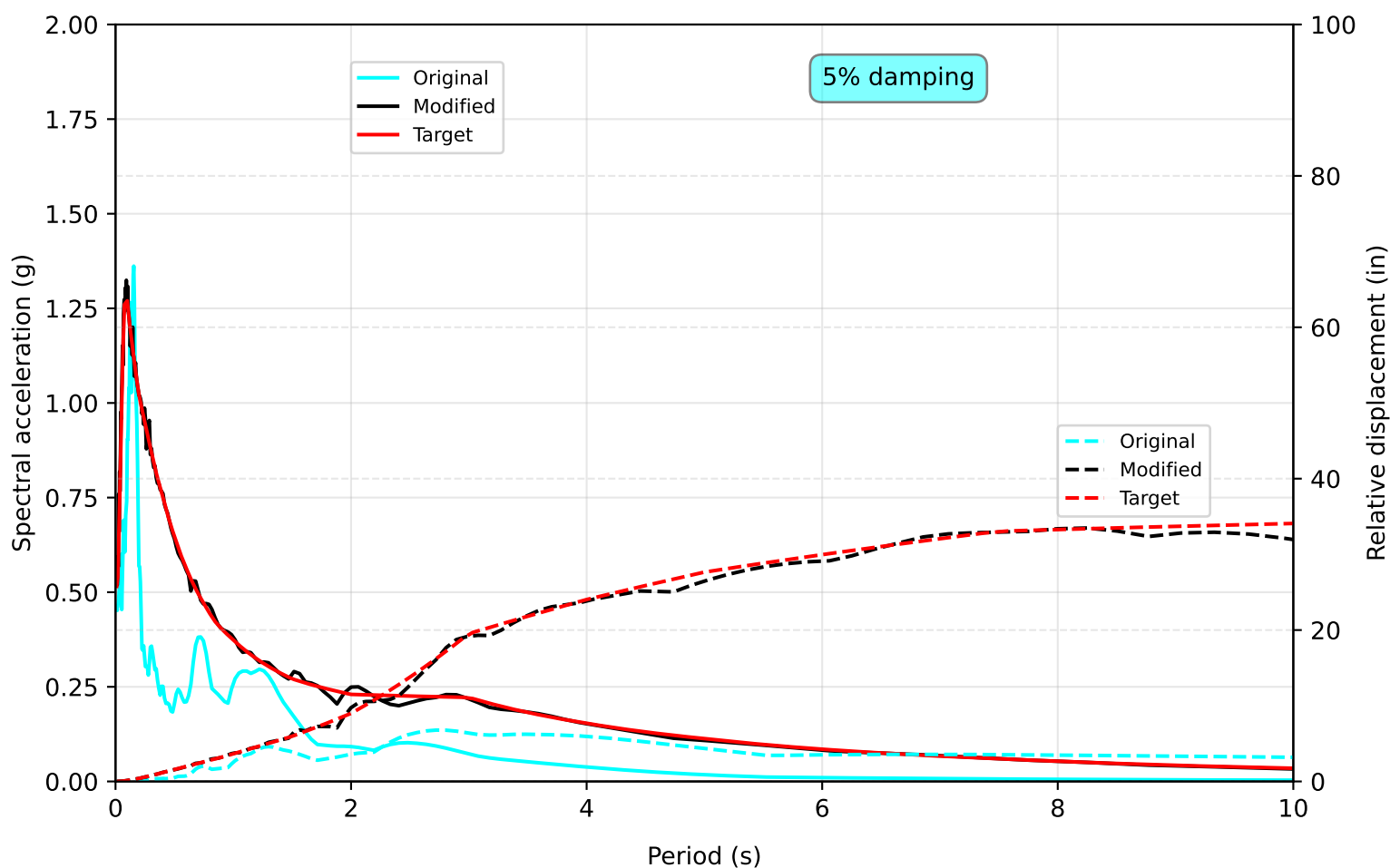
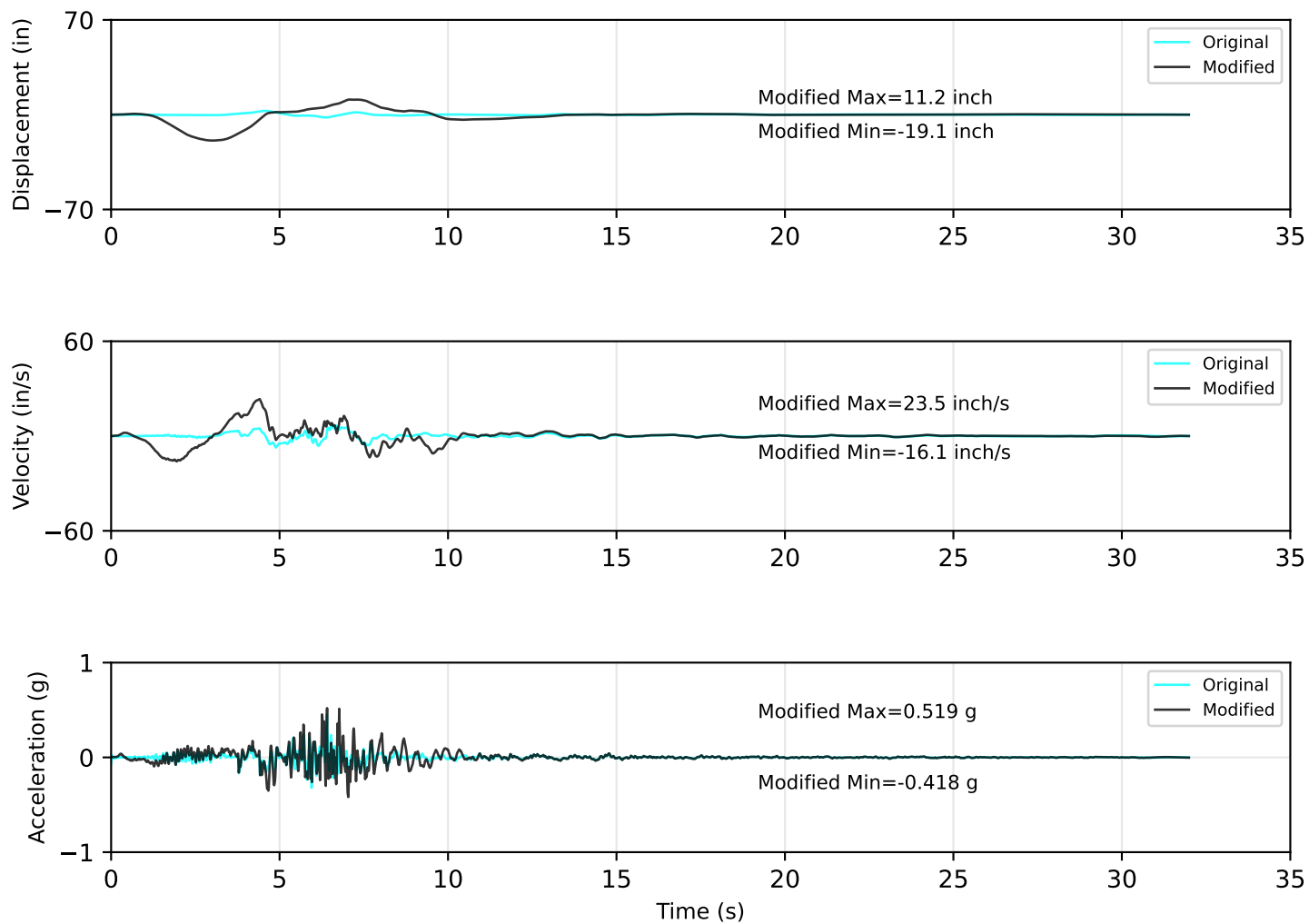


Figure E42. Unimproved Ground ASCE 7-22 DE Spectrum-matched Ground Motion - Set-7 Vertical