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Probabilistic Seismic Hazards Update for LLNL

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COVER SHEET

PROBABILISTIC SEISMIC HAZARDS UPDATE FOR LLNL: EXECUTIVE SUMMARY REPORT

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LLNL

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VERIFICATION SUMMARY SHEET

Item	Parameter	Yes	No	N/A
1	Purpose is clearly stated and Report satisfies the Purpose.	X		
2	Methodology is appropriate and properly applied.	X		
3	Assumptions are reasonable, adequately described, and based upon sound geotechnical principles and practices.	X		
4	Input was authorized and correctly incorporated into the Report.	X		
5	Software is properly identified and applied; and validation is referenced, or included, and acceptable.			X
6	Detailed Discussion is complete, accurate, and leads logically to Results and Conclusions.	X		
7	Results and Conclusions are accurate, acceptable, and reasonable compared to the Input and Assumptions.	X		
8	If commercial software, such as EXCEL, MATLAB, IDL, or Mathcad, was used, equations and other entries have been checked as necessary to ensure correct results.			X
9	References are valid for intended use.	X		
10	Appendices are complete, accurate, and support text.			X

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1.0 INTRODUCTION

1.1 BACKGROUND

Fugro Consultants, Inc. (FCL) completed the Probabilistic Seismic Hazard Analysis (PSHA) performed for Building 332 at the Lawrence Livermore National Laboratory (LLNL), near Livermore, CA. The study performed for the LLNL site includes a comprehensive review of recent information relevant to the LLNL regional tectonic setting and regional seismic sources in the vicinity of the site and development of seismic wave transmission characteristics. The Seismic Source Characterization (SSC), documented in Project Report No. 2259-PR-02 (FCL, **2015b**), and Ground Motion Characterization (GMC), documented in Project Report No. 2259-PR-06 (FCL, **2015a**) were developed in accordance with ANS/ANSI 2.29-2008 Level 2 PSHA guidelines. The ANS/ANSI 2.29-2008 Level 2 PSHA framework is documented in Project Report No. 2259-PR-05 (FCL, **2016a**). The Hazard Input Document (HID) for input into the PSHA developed from the SSC and GMC is presented in Project Report No. 2259-PR-04 (FCL, **2016b**). The site characterization used as input for development of the idealized site profiles including epistemic uncertainty and aleatory variability is presented in Project Report No. 2259-PR-03 (FCL, **2015c**). The PSHA results are documented in Project Report No. 2259-PR-07 (FCL, **2016c**).

The SSC was primarily derived from the Uniform California Earthquake Rupture Forecast, Version 3 (UCERF3) seismic source model (Field et al., 2013). More details on the SSC and HID are presented in FCL (**2015b**) and FCL (**2016b**), respectively. The horizontal GMC was developed from the NGA West 2 Ground Motion Prediction Equations (GMPEs) (Abrahamson et al., 2014 [ASK14]; Boore et al., 2014 [BSSA14]; Campbell and Bozorgnia; 2014 [CB14]; Chiou and Youngs, 2013 [CY13], and Idriss, 2013 [I13]), an epistemic uncertainty model from Al Atik and Youngs (2013), the single-station sigma model from BC Hydro (2012), and a directivity model of Bayless and Somerville (in Spudich et al., 2013). The vertical GMC is based on development of Vertical-to-Horizontal (V/H) scaling relations. More details on the GMC are presented in FCL (**2015a**). The half-space and idealized site profiles for input into the GMC were presented in FCL (**2015c**).

A site response analysis was performed to provide site amplification factors for the PSHA and to develop the appropriate Soil-Structure-Interaction (SSI) inputs in the form of strain compatible site dynamic profiles and parameters. The final result of the study is the development of the final design spectra based on ASCE/SEI 43-05 (ASCE, 2005) for Seismic Design Criteria (SDC) SDC-3, while SDC-1 and SDC-2 were developed in accordance with ASCE/SEI 7-10 (ASCE, 2010) per the requirements of DOE-STD-1020-2012 (USDOE, 2012). In addition, SDC-3 with reduced hazard is also developed based on relaxed earthquake criterion as allowed by DOE-STD-1020-2012 (USDOE, 2012) Section 9.3.6 for existing facilities. The SDC-3 with reduced hazard uses half the hazard level of SDC-3, but limits reduction in the design response spectra to 20% of SDC-3. A suite of ten 3-component acceleration time histories were developed and presented for SDC-3. The PSHA results are summarized in FCL (**2016c**).

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The conclusions of this study were targeted towards Building 332 explicitly and do not claim to be applicable to other areas at LLNL.

1.2 LIST OF DELIVERABLES

The PSHA report was split into six project reports documenting different tasks of the scope of work. The PSHA study is the combination of all six reports and should be considered as one deliverable consisting of six components. The six reports are as follows:

1. Fugro Consultants, Inc. (FCL) (**2016a**). Probabilistic Seismic Hazards Update for LLNL: ANSI/ANS 2.29 (2008) Level 2 Framework Summary Report, Project Report No. 2259-PR-05, Rev. 1.

   Provides documentation per ANSI/ANS 2.29 (2008) of SSC and GMC resource and proponent interactions in addition to DNFSB and Participatory Peer Review Panel (PPRP) comment/response documents.

2. Fugro Consultants, Inc. (FCL) (**2015c**). Probabilistic Seismic Hazard Update for LLNL: Site Characterization Report, Project Report No. 2259-PR-03, Rev. 2.

   Provides documentation of prior LLNL site characterization data, evaluation of those data, final geophysical investigation results, and use of these data to generate the site characterization dynamic model incorporating both epistemic uncertainty and aleatory variability.

3. Fugro Consultants, Inc. (FCL) (**2015b**). Probabilistic Seismic Hazard Update for LLNL: Seismic Source Characterization Report, Project Report No. 2259-PR-02, Rev. 1.

   Provides documentation of LLNL's SSC developed based on UCERF3 (Field et al., 2013).

4. Fugro Consultants, Inc. (FCL) (**2016b**). Probabilistic Seismic Hazard Update for LLNL: Hazard Implementation Document, Project Report No. 2259-PR-04, Rev. 1.

   Provides documentation of the HID for guidance on implementation of the SSC.

5. Fugro Consultants, Inc. (FCL) (**2015a**). Probabilistic Seismic Hazard Update for LLNL: Ground Motion Characterization Report, Project Report No. 2259-PR-06, Rev. 2.

   Provides documentation of LLNL's GMC developed.

6. Fugro Consultants, Inc. (FCL) (**2016c**). Probabilistic Seismic Hazard Update for LLNL: PSHA Results, Project Report No. 2259-PR-07, Rev. 1.

   Documents the results of the PSHA, development of the design response spectra, strain compatible soil profiles, and acceleration time histories.

1.3 SITE CHARACTERIZATION AND GEOPHYSICAL INVESTIGATION RESULTS

A comprehensive review of the site characterization of the LLNL Building 332 site was completed and included in the Site Characterization Report (FCL, **2015c**). The report provides a summary and evaluation

of prior LLNL site characterization data, discusses and integrates new geophysical data acquired for Building 332 with prior LLNL site data, and provides three idealized site profile base cases representing epistemic uncertainty in addition to assessment of the corresponding aleatory variability. The new geophysics data for Building 332 included Interferometric Multichannel Analysis of Surface Waves (IMASW) and Refraction Tomography (RT) surveys.

The site characterization and its incorporation into the PSHA followed the philosophy related to the development of base-case profiles presented in Appendix B of the EPRI (2013) SPID report. The epistemic uncertainty was captured by developing three base case shear wave velocity profiles (BC1, BC2, and BC3) based on analysis and review of the geophysical data collected. Aleatory variability for each of the three base cases was creating a consistent model whereby the scatter between the lower and upper bound values of the interpreted shear wave velocity data was captured within the 16th percentile of the distribution around the lower bound idealized base case profile (BC1) and the 84th percentile of the distribution around the upper bound idealized base case profile (BC3). More details on capturing the aleatory variability of the shear wave velocity data are included in FCL (**2015c**).

1.4 SEISMIC SOURCE CHARACTERIZATION

The SSC was developed in accordance with ANSI/ANS 2.29 (2008) Level 2 PSHA as documented in FCL (**2016a**). The UCERF3 (Field et al., 2013) seismic source model is the base source model used in the LLNL PSHA. The UCERF3 model "provides authoritative estimates of magnitude, location, and time-averaged frequency of potentially damaging earthquakes in California" (Field et al., 2013) and represents a multi-year collaborative effort within the California scientific community to update the prior time-independent seismic hazard models (UCERF2). The UCERF3 (Field et al., 2013) model is a regional seismic source model that provided the starting framework for the seismic source evaluation of the LLNL site. Prior PSHA studies (discussed in FCL [**2016c**]) and updated screening evaluations of the LLNL site (FCL, **2016c**) demonstrate that the dominant source contributions come from sources close to the LLNL site (mostly within 40 km), and therefore, the UCERF3 (Field et al., 2013) model was used for regional sources, and additional sources were added to encompass the site-specific PSHA (FCL, **2016c**).

Key components of the UCERF3 (Field et al., 2013) model include: (1) increased fault participation in connected (complex multi-fault) rupture scenarios, based on geologic and geophysical criteria (2) increased utilization of geodetic data (3) increased application of aseismic factors (4) a "grand inversion" approach, where instead of deterministic slip rates assigned to each fault, the rates of all earthquakes on all faults are solved for simultaneously, with the goal of best fitting the geodetic and geologic observations. Magnitude-frequency forms are also not assigned, but derived from the inversion (5) a method of characterizing "off-fault" (background) seismicity that relies on differences between the state-wide seismicity moment rate and the fault-based moment rate, instead of relying directly on spatially smoothing non-fault related seismicity, and (6) elimination of the "rate bulge" for magnitude 6.5-7 earthquakes. This is the misfit between historic seismicity rates and fault-based recurrence rates in the UCERF2 model.

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A comprehensive review of the tectonic setting and seismic sources of the LLNL site was completed and is included in the SSC report (FCL, **2015b**). The SSC report includes a review of the UCERF3 (Field et al., 2013) model, a summary of prior PSHA studies conducted for the LLNL site, and determines the need for updating the UCERF3 regional model with sources close to the LLNL site for the LLNL site-specific PSHA. The SSC inputs into the HID are presented in FCL (**2016b**).

1.5 GROUND MOTION CHARACTERIZATION

The GMC was developed in accordance with ANSI/ANS 2.29 (2008) Level 2 PSHA as documented in FCL (**2016a**). Development of the GMC included reviewing Ground Motion Prediction Equations (GMPEs) used in the latest PSHA study for the project (Savy and Foxall, 2002), identifying tectonic regime governing seismicity at the project site, identifying candidate GMPEs suitable for use in the PSHA, identifyinf the half space depth for application of the GMPEs, evaluating the applicability of the candidate GMPEs for use in the applicable tectonic regime for LLNL, determining appropriate weights for the GMPEs, evaluating the inclusion of additional epistemic uncertainty, evaluating the use of single-station sigmas, evaluating the incorporation of appropriate directivity models and potential impact on the standard deviations, and evaluating the optimal method for generating vertical spectra.

The horizontal GMC was developed from the NGA West 2 Ground Motion Prediction Equations (GMPEs) (Abrahamson et al., 2014 [ASK14]; Boore et al., 2014 [BSSA14]; Campbell and Bozorgnia; 2014 [CB14]; Chiou and Youngs, 2013 [CY13], and Idriss, 2013 [I13]), an epistemic uncertainty model from Al Atik and Youngs (2013), the single-station sigma model from BC Hydro (2012), and a directivity model of Bayless and Somerville (in Spudich et al., 2013). The vertical GMC is based on development of Vertical-to-Horizontal (V/H) scaling relations. More details on the GMC are presented in FCL (**2015a**). GMC inputs into the HID are presented in FCL (**2016b**).

1.6 PROBABILISTIC SEISMIC HAZARD ANALYSIS RESULTS

The PSHA Results Report (FCL, **2016c**) describes the PSHA calculations performed for the LLNL site using FCL's FRISK88 software suite developed under FCL's QA program (FCL, 2014a through 2014e), including PSHA sensitivity calculations and other calculations supporting the decision not to incorporate the ground motion directivity effects branch in the GMC logic tree (FCL, **2015a**; FCL, **2016b**). The report included the calculation of half-space rock seismic hazard at the LLNL site, PSHA sensitivity calculations, a deaggregation of the half-space rock seismic hazard, determination of controlling earthquakes, and the calculation of high- and low-frequency horizontal half-space rock response spectra.

A site response analysis was performed to provide site amplification factors for the PSHA and to develop the appropriate SSI inputs in the form of strain compatible site dynamic profiles and parameters. The final design spectra were presented based on ASCE/SEI 43-05 (ASCE, 2005) for Seismic Design Criteria (SDC) SDC-3 , while SDC-1 and SDC-2 were developed in accordance with ASCE/SEI 7-10 (ASCE, 2010) per the requirements of DOE-STD-1020-2012 (USDOE, 2012). In addition, SDC-3 with reduced

hazard is also developed based on relaxed earthquake criterion as allowed by DOE-STD-1020-2012 (USDOE, 2012) Section 9.3.6 for existing facilities. The SDC-3 with reduced hazard uses half the hazard level of SDC-3, but limits reduction in the design response spectra to 20% of SDC-3. The vertical motions were then developed using V/H scaling relations. A suite of ten 3-component acceleration time histories were developed and presented for SDC-3.

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2.0 SUMMARY AND RECOMMENDATIONS

2.1 SUMMARY

The study performed for the LLNL site by FCL included a comprehensive review of recent information relevant to the LLNL regional tectonic setting and regional seismic sources in the vicinity of the site and development of seismic wave transmission characteristics.

The largest contributor to the hazard at the LLNL site is the Greenville North fault. A comparison of the horizontal ASCE 7-10 (ASCE, 2010) DBE, ASCE 7-10 (ASCE, 2010) MCE_R, and SDC-3 response spectra for 5% damping ratio to the surface soil UHRS presented in Savy and Foxall (2002) indicated that for frequencies above about 5 Hz, there is a good comparison between the ASCE 7-10 (ASCE, 2010) DBE and MCE_R response spectra and the soil UHRS from Savy and Foxall (2002) for return periods of 500 and 2,000 years, respectively.

2.2 COMPARISON TO PREVIOUS STUDIES

In Coats (1991), the horizontal design response spectra for the LLNL Site were defined as using a Newmark-Hall type spectra using “effective accelerations” as the spectra. The “effective accelerations” concept was adopted to reduce the earthquake demands by accounting for SSI effects of near-source ground motions events of short duration and high peak accelerations. The “effective accelerations” reduction factor developed at the LLNL Site was 0.83. The unmodified PGAs at the project site based on the 1991 Geomatrix study (Geomatrix, 1991) were 0.567g, 0.682g, and 0.983g for 500, 1000, and 5000 years, respectively. This compares to unmodified surface PGAs derived in the current 2014 FCL PSHA study of 0.532g, 0.668g, and 0.9711g for the same three return periods (FCL, **2016c**), which are comparable. Based on Coats (1991), the design spectra for the LLNL Site were then defined as Newmark-Hall type spectra anchored at PGAs of 0.471g, 0.566g, and 0.816g for the three return periods (500, 1000, and 5000 years), respectively. Building 332 corresponded to the 1000 year return period standard and as such the PGA used was 0.566g. This could be compared to the PGA for the LLNL Site based on the 2014 study with values of of 0.673g for SDC-3 and 0.571g for SDC-3 with the reduced hazard, which corresponds to increases of 19% and 1%, respectively.

Savy and Foxall (2002) performed an updated PSHA. Their mean hazard estimates were essentially identical to the mean hazard estimates developed by Geomatrix (1991) in spite of the different approaches in treatment of uncertainties, different set of alternative tectonic models, and the different set of GMPEs adopted. The surface soil UHRS in the current 2014 PSHA study indicates that the mean values of PGA are comparable, similar to the comparison with the 1991 Geomatrix study above.

DOE-STD-1020-2002 (USDOE, 2002) was the applicable standard for LLNL facilities as defined in the LLNL Structural Design Manual for PC-3 and PC-4 structures (LLNL, 2007). For PC-3 structures (applicable to Building 332), the PGA adopted to anchor the design spectra incorporates the effective acceleration factor of 0.83 multiplied by the Savy and Foxall (2002) generic soil PGA resulting a design PGA of 0.57g, effectively unchanged from the 1991 studies. The PGA for surface soil SDC-3 and SDC-3 with the reduced hazard at the LLNL Site are thus 19% and 1% higher. For the vertical motion, the

vertical DBE was considered the same as the horizontal DBE (LLNL, 2007). In the 2014 PSHA study, the vertical DBE is higher at intermediate frequencies (in the 9 to 40 Hz range) and lower at other frequencies.

A preliminary study evaluating the development of ASCE 43-05 SDC-3 at the LLNL was performed by Geomatrix (2005). This study was based on the Savy and Foxall (2002) PSHA results. They estimated the ASCE 43-05 design factor as 0.8 and recommended using it to scale the 5% spectra interpolated for the $4x10^{-4}$ AFE hazard level. This results in an estimated design PGA for SDC-3 of 0.656g. The PGA for SDC-3 in this 2014 PSHA study is 0.673g, representing an increase of only 3%. If the SDC-3 with the reduced hazard design spectrum is used, the PGA from the 2014 PSHA study is actually 13% lower. The 2014 PSHA study explicitly incorporates site-specific uncertainties and adopted a more rigorous and detailed framework for the SSC and GMC logic tree.

The design response spectra are presented in Tables 2-1 through 2-8 and Figures 2-1 through 2-3.

2.3 RECOMMENDATIONS

PSHA, SSI inputs, understanding and evaluating risk, and inputs into SSC and GMC are an ever evolving field with constant ongoing research. While updates are usually governed by regulatory agencies (like the USDOE), it is recommended that stakeholders perform qualitative evaluations when new information and research models become available to evaluate the need to update the current study.

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TABLES

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Table 2-1. Horizontal Surface Soil ASCE 7-10 DBE Response Spectra for Different Damping Ratios at the LLNL Site

Period (sec)	Freq. (Hz)	Horizontal Spectral Acceleration (g)							
		0.5%	2%	3%	4%	5%	7%	10%	15%
PGA		0.563	0.564	0.564	0.564	0.564	0.564	0.563	0.563
0.010	100.00	0.567	0.567	0.567	0.567	0.567	0.567	0.567	0.566
0.011	90.00	0.570	0.569	0.569	0.568	0.568	0.567	0.567	0.566
0.013	80.00	0.574	0.571	0.570	0.569	0.569	0.568	0.567	0.566
0.014	70.00	0.578	0.573	0.572	0.571	0.570	0.569	0.568	0.566
0.017	60.00	0.583	0.576	0.574	0.573	0.572	0.570	0.569	0.567
0.020	50.00	0.591	0.581	0.579	0.577	0.575	0.573	0.571	0.569
0.022	45.00	0.611	0.591	0.586	0.582	0.580	0.576	0.573	0.569
0.025	40.00	0.635	0.603	0.595	0.590	0.586	0.581	0.576	0.571
0.029	35.00	0.665	0.619	0.608	0.600	0.595	0.588	0.581	0.574
0.033	30.00	0.724	0.651	0.634	0.623	0.615	0.604	0.593	0.582
0.040	25.00	0.815	0.701	0.675	0.658	0.646	0.629	0.613	0.596
0.050	20.00	0.946	0.775	0.736	0.711	0.694	0.668	0.644	0.620
0.067	15.00	1.169	0.909	0.849	0.809	0.779	0.740	0.700	0.659
0.075	13.33	1.289	0.984	0.912	0.865	0.829	0.782	0.734	0.684
0.080	12.50	1.352	1.029	0.951	0.900	0.861	0.809	0.756	0.701
0.100	10.00	1.572	1.186	1.087	1.021	0.969	0.900	0.829	0.753
0.111	9.00	1.688	1.267	1.157	1.083	1.025	0.948	0.868	0.784
0.125	8.00	1.807	1.348	1.226	1.143	1.080	0.993	0.904	0.810
0.143	7.00	1.939	1.437	1.302	1.209	1.138	1.040	0.941	0.835
0.150	6.67	1.994	1.474	1.333	1.237	1.163	1.061	0.956	0.846
0.167	6.00	2.069	1.531	1.381	1.278	1.199	1.089	0.977	0.858
0.200	5.00	2.216	1.642	1.475	1.360	1.271	1.146	1.019	0.884
0.250	4.00	2.343	1.754	1.575	1.451	1.352	1.219	1.080	0.932
0.300	3.33	2.354	1.806	1.628	1.502	1.405	1.263	1.118	0.962
0.333	3.000	2.402	1.853	1.672	1.542	1.442	1.295	1.145	0.984
0.400	2.50	2.305	1.796	1.621	1.496	1.397	1.254	1.106	0.947
0.500	2.00	2.106	1.666	1.508	1.393	1.303	1.171	1.034	0.886
0.667	1.50	1.818	1.463	1.327	1.227	1.148	1.029	0.907	0.773
0.750	1.33	1.717	1.392	1.263	1.168	1.093	0.979	0.862	0.734

Period (sec)	Freq. (Hz)	Horizontal Spectral Acceleration (g)							
		0.5%	2%	3%	4%	5%	7%	10%	15%
0.800	1.25	1.637	1.337	1.216	1.126	1.055	0.947	0.834	0.712
1.000	1.00	1.342	1.126	1.032	0.961	0.904	0.816	0.723	0.621
1.111	0.90	1.206	1.014	0.930	0.866	0.816	0.737	0.654	0.563
1.250	0.80	1.059	0.893	0.820	0.765	0.720	0.652	0.579	0.499
1.429	0.70	0.908	0.768	0.706	0.659	0.621	0.563	0.501	0.433
1.500	0.67	0.842	0.713	0.656	0.612	0.577	0.524	0.466	0.403
1.667	0.60	0.705	0.601	0.554	0.519	0.490	0.446	0.398	0.346
2.000	0.50	0.518	0.448	0.415	0.390	0.370	0.338	0.303	0.265
2.500	0.40	0.384	0.335	0.313	0.295	0.281	0.258	0.233	0.205
3.000	0.33	0.301	0.266	0.249	0.235	0.225	0.207	0.189	0.167
3.333	0.30	0.262	0.233	0.218	0.207	0.198	0.183	0.167	0.148
4.000	0.25	0.211	0.190	0.179	0.170	0.163	0.151	0.138	0.123
5.000	0.20	0.169	0.156	0.148	0.141	0.136	0.126	0.116	0.103
6.667	0.15	0.118	0.109	0.103	0.098	0.095	0.088	0.081	0.073
7.500	0.13	0.102	0.094	0.089	0.085	0.082	0.077	0.071	0.064
8.000	0.13	0.090	0.083	0.079	0.076	0.074	0.069	0.064	0.058
10.000	0.10	0.055	0.053	0.051	0.050	0.048	0.046	0.043	0.039

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Table 2-2. Vertical Surface Soil ASCE 7-10 DBE Response Spectra for Different Damping Ratios at the LLNL Site

Period (sec)	Freq. (Hz)	Vertical Spectral Acceleration (g)							
		0.5%	2%	3%	4%	5%	7%	10%	15%
PGA		0.401	0.401	0.401	0.401	0.401	0.400	0.400	0.400
0.010	100.00	0.401	0.401	0.401	0.401	0.401	0.400	0.400	0.400
0.011	90.00	0.415	0.412	0.411	0.411	0.410	0.410	0.409	0.408
0.013	80.00	0.430	0.425	0.423	0.422	0.421	0.420	0.418	0.416
0.014	70.00	0.449	0.440	0.437	0.435	0.434	0.432	0.429	0.427
0.017	60.00	0.472	0.458	0.454	0.451	0.449	0.446	0.443	0.439
0.020	50.00	0.508	0.488	0.482	0.478	0.475	0.470	0.466	0.460
0.022	45.00	0.573	0.528	0.517	0.509	0.503	0.495	0.486	0.477
0.025	40.00	0.663	0.586	0.567	0.555	0.545	0.532	0.518	0.504
0.029	35.00	0.777	0.658	0.629	0.610	0.595	0.575	0.555	0.534
0.033	30.00	0.973	0.783	0.736	0.706	0.683	0.651	0.620	0.587
0.040	25.00	1.267	0.962	0.888	0.840	0.802	0.753	0.703	0.651
0.050	20.00	1.673	1.197	1.081	1.005	0.947	0.870	0.793	0.712
0.067	15.00	1.963	1.383	1.233	1.132	1.056	0.952	0.848	0.739
0.075	13.33	2.084	1.460	1.294	1.183	1.099	0.983	0.867	0.746
0.080	12.50	2.070	1.444	1.278	1.166	1.082	0.966	0.849	0.729
0.100	10.00	1.887	1.301	1.144	1.038	0.960	0.849	0.740	0.628
0.111	9.00	1.800	1.241	1.091	0.990	0.915	0.808	0.704	0.597
0.125	8.00	1.715	1.183	1.040	0.943	0.871	0.769	0.669	0.566
0.143	7.00	1.576	1.088	0.955	0.866	0.800	0.705	0.613	0.518
0.150	6.67	1.512	1.044	0.917	0.831	0.767	0.676	0.588	0.496
0.167	6.00	1.369	0.959	0.845	0.767	0.709	0.627	0.546	0.462
0.200	5.00	1.178	0.847	0.750	0.684	0.633	0.563	0.492	0.417
0.250	4.00	1.047	0.764	0.680	0.622	0.578	0.515	0.451	0.384
0.300	3.33	1.020	0.751	0.670	0.613	0.571	0.509	0.447	0.381
0.333	3.000	1.020	0.759	0.679	0.623	0.579	0.517	0.454	0.388
0.400	2.50	0.918	0.699	0.627	0.576	0.536	0.480	0.422	0.360
0.500	2.00	0.734	0.561	0.504	0.463	0.432	0.387	0.341	0.291
0.667	1.50	0.555	0.436	0.393	0.363	0.339	0.303	0.266	0.227
0.750	1.33	0.514	0.409	0.369	0.341	0.318	0.285	0.250	0.213

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Period (sec)	Freq. (Hz)	Vertical Spectral Acceleration (g)							
		0.5%	2%	3%	4%	5%	7%	10%	15%
0.800	1.25	0.498	0.396	0.358	0.331	0.309	0.276	0.243	0.207
1.000	1.00	0.437	0.350	0.317	0.293	0.274	0.246	0.216	0.184
1.111	0.90	0.391	0.316	0.286	0.265	0.248	0.222	0.196	0.167
1.250	0.80	0.340	0.276	0.251	0.233	0.218	0.196	0.173	0.148
1.429	0.70	0.288	0.236	0.215	0.200	0.187	0.168	0.149	0.127
1.500	0.67	0.268	0.221	0.201	0.187	0.175	0.158	0.139	0.119
1.667	0.60	0.233	0.193	0.176	0.164	0.154	0.138	0.122	0.105
2.000	0.50	0.184	0.155	0.142	0.132	0.124	0.112	0.099	0.085
2.500	0.40	0.142	0.122	0.113	0.106	0.100	0.091	0.081	0.070
3.000	0.33	0.114	0.101	0.094	0.088	0.084	0.076	0.068	0.059
3.333	0.30	0.100	0.090	0.084	0.079	0.075	0.068	0.061	0.053
4.000	0.25	0.082	0.074	0.070	0.066	0.063	0.057	0.052	0.045
5.000	0.20	0.065	0.060	0.057	0.054	0.051	0.047	0.043	0.037
6.667	0.15	0.046	0.044	0.042	0.040	0.039	0.036	0.033	0.030
7.500	0.13	0.040	0.038	0.037	0.035	0.034	0.032	0.030	0.027
8.000	0.13	0.036	0.034	0.033	0.032	0.031	0.029	0.027	0.025
10.000	0.10	0.023	0.022	0.022	0.021	0.020	0.019	0.018	0.017

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Table 2-3. Horizontal Surface Soil ASCE 7-10 MCE_R Response Spectra for Different Damping Ratios at the LLNL Site

Period (sec)	Freq. (Hz)	Horizontal Spectral Acceleration (g)							
		0.5%	2%	3%	4%	5%	7%	10%	15%
PGA		0.845	0.846	0.846	0.846	0.846	0.845	0.845	0.845
0.010	100.00	0.850	0.851	0.851	0.851	0.851	0.850	0.850	0.850
0.011	90.00	0.855	0.853	0.853	0.852	0.852	0.851	0.850	0.849
0.013	80.00	0.860	0.856	0.855	0.854	0.853	0.852	0.851	0.849
0.014	70.00	0.867	0.860	0.858	0.856	0.855	0.854	0.852	0.850
0.017	60.00	0.875	0.864	0.862	0.859	0.858	0.855	0.853	0.850
0.020	50.00	0.887	0.872	0.868	0.865	0.863	0.860	0.857	0.853
0.022	45.00	0.916	0.886	0.878	0.873	0.870	0.864	0.859	0.853
0.025	40.00	0.953	0.905	0.893	0.885	0.880	0.872	0.864	0.856
0.029	35.00	0.997	0.928	0.911	0.901	0.893	0.882	0.871	0.861
0.033	30.00	1.083	0.974	0.948	0.932	0.920	0.903	0.887	0.871
0.040	25.00	1.214	1.045	1.006	0.981	0.963	0.937	0.913	0.889
0.050	20.00	1.405	1.151	1.094	1.057	1.030	0.993	0.957	0.921
0.067	15.00	1.748	1.360	1.269	1.210	1.165	1.106	1.046	0.985
0.075	13.33	1.932	1.474	1.366	1.296	1.241	1.171	1.099	1.024
0.080	12.50	2.024	1.540	1.424	1.347	1.288	1.211	1.132	1.049
0.100	10.00	2.330	1.758	1.611	1.512	1.436	1.334	1.228	1.116
0.111	9.00	2.487	1.866	1.704	1.595	1.510	1.396	1.279	1.154
0.125	8.00	2.688	2.005	1.824	1.701	1.606	1.477	1.345	1.205
0.143	7.00	2.904	2.152	1.949	1.811	1.704	1.558	1.408	1.250
0.150	6.67	2.989	2.210	1.998	1.854	1.743	1.590	1.434	1.268
0.167	6.00	3.104	2.297	2.072	1.917	1.799	1.634	1.465	1.287
0.200	5.00	3.325	2.464	2.213	2.040	1.907	1.719	1.528	1.325
0.250	4.00	3.515	2.631	2.363	2.177	2.028	1.828	1.620	1.398
0.300	3.33	3.531	2.708	2.442	2.253	2.107	1.894	1.676	1.443
0.333	3.000	3.603	2.780	2.508	2.314	2.162	1.943	1.717	1.475
0.400	2.50	3.458	2.694	2.432	2.244	2.095	1.881	1.659	1.420
0.500	2.00	3.159	2.499	2.262	2.090	1.955	1.757	1.551	1.328
0.667	1.50	2.728	2.195	1.991	1.840	1.722	1.544	1.360	1.160
0.750	1.33	2.576	2.088	1.895	1.752	1.640	1.469	1.293	1.101

Period (sec)	Freq. (Hz)	Horizontal Spectral Acceleration (g)							
		0.5%	2%	3%	4%	5%	7%	10%	15%
0.800	1.25	2.455	2.005	1.824	1.688	1.582	1.420	1.251	1.068
1.000	1.00	2.013	1.689	1.548	1.441	1.356	1.224	1.085	0.932
1.111	0.90	1.808	1.521	1.395	1.299	1.224	1.106	0.981	0.844
1.250	0.80	1.589	1.340	1.230	1.147	1.080	0.978	0.869	0.749
1.429	0.70	1.362	1.152	1.059	0.988	0.931	0.844	0.752	0.649
1.500	0.67	1.264	1.070	0.984	0.918	0.865	0.785	0.700	0.605
1.667	0.60	1.057	0.901	0.832	0.778	0.735	0.668	0.597	0.518
2.000	0.50	0.776	0.671	0.623	0.585	0.555	0.506	0.455	0.398
2.500	0.40	0.576	0.503	0.469	0.442	0.421	0.386	0.350	0.308
3.000	0.33	0.452	0.399	0.373	0.353	0.337	0.311	0.283	0.251
3.333	0.30	0.393	0.349	0.327	0.310	0.296	0.274	0.250	0.222
4.000	0.25	0.317	0.285	0.269	0.255	0.244	0.227	0.207	0.185
5.000	0.20	0.253	0.234	0.221	0.211	0.203	0.189	0.173	0.155
6.667	0.15	0.175	0.162	0.154	0.147	0.141	0.132	0.121	0.109
7.500	0.13	0.152	0.140	0.133	0.127	0.122	0.114	0.105	0.095
8.000	0.13	0.133	0.124	0.118	0.113	0.109	0.102	0.095	0.086
10.000	0.10	0.082	0.079	0.077	0.074	0.072	0.068	0.064	0.059

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Table 2-4. Vertical Surface Soil ASCE 7-10 MCE_R Response Spectra for Different Damping Ratios at the LLNL Site

Period (sec)	Freq. (Hz)	Vertical Spectral Acceleration (g)							
		0.5%	2%	3%	4%	5%	7%	10%	15%
PGA		0.591	0.592	0.592	0.591	0.591	0.591	0.591	0.590
0.010	100.00	0.594	0.594	0.594	0.594	0.594	0.594	0.593	0.593
0.011	90.00	0.609	0.605	0.604	0.603	0.603	0.602	0.600	0.599
0.013	80.00	0.626	0.618	0.616	0.614	0.613	0.610	0.608	0.606
0.014	70.00	0.647	0.633	0.629	0.627	0.624	0.621	0.618	0.614
0.017	60.00	0.671	0.651	0.646	0.642	0.639	0.634	0.629	0.624
0.020	50.00	0.714	0.685	0.677	0.672	0.667	0.661	0.654	0.647
0.022	45.00	0.803	0.740	0.724	0.714	0.705	0.694	0.682	0.669
0.025	40.00	0.928	0.821	0.794	0.777	0.763	0.744	0.726	0.705
0.029	35.00	1.086	0.920	0.880	0.853	0.833	0.805	0.777	0.747
0.033	30.00	1.358	1.092	1.028	0.985	0.953	0.909	0.865	0.819
0.040	25.00	1.765	1.340	1.237	1.169	1.118	1.049	0.979	0.906
0.050	20.00	2.327	1.664	1.503	1.398	1.317	1.210	1.102	0.989
0.067	15.00	2.721	1.917	1.708	1.569	1.463	1.319	1.175	1.025
0.075	13.33	2.901	2.032	1.801	1.646	1.529	1.368	1.206	1.039
0.080	12.50	2.929	2.044	1.809	1.651	1.532	1.367	1.202	1.032
0.100	10.00	2.804	1.933	1.700	1.543	1.427	1.262	1.100	0.933
0.111	9.00	2.700	1.862	1.636	1.485	1.372	1.213	1.056	0.895
0.125	8.00	2.572	1.775	1.559	1.414	1.307	1.154	1.004	0.849
0.143	7.00	2.364	1.632	1.433	1.299	1.200	1.058	0.920	0.777
0.150	6.67	2.268	1.566	1.375	1.246	1.151	1.015	0.881	0.744
0.167	6.00	2.053	1.438	1.267	1.151	1.064	0.941	0.819	0.693
0.200	5.00	1.765	1.268	1.124	1.024	0.949	0.843	0.736	0.625
0.250	4.00	1.544	1.126	1.003	0.917	0.853	0.759	0.665	0.567
0.300	3.33	1.459	1.073	0.958	0.877	0.817	0.728	0.639	0.546
0.333	3.000	1.449	1.079	0.965	0.885	0.823	0.735	0.646	0.551
0.400	2.50	1.343	1.022	0.917	0.843	0.784	0.702	0.617	0.526
0.500	2.00	1.090	0.833	0.749	0.689	0.642	0.575	0.506	0.433
0.667	1.50	0.826	0.649	0.586	0.540	0.504	0.451	0.396	0.338
0.750	1.33	0.766	0.609	0.550	0.508	0.474	0.424	0.373	0.317

Period (sec)	Freq. (Hz)	Vertical Spectral Acceleration (g)							
		0.5%	2%	3%	4%	5%	7%	10%	15%
0.800	1.25	0.742	0.591	0.535	0.493	0.461	0.412	0.362	0.308
1.000	1.00	0.655	0.525	0.476	0.439	0.411	0.368	0.324	0.276
1.111	0.90	0.587	0.473	0.430	0.397	0.372	0.334	0.294	0.251
1.250	0.80	0.510	0.414	0.377	0.349	0.327	0.294	0.259	0.221
1.429	0.70	0.432	0.354	0.323	0.299	0.281	0.253	0.223	0.191
1.500	0.67	0.402	0.331	0.302	0.280	0.263	0.237	0.209	0.179
1.667	0.60	0.349	0.289	0.264	0.245	0.231	0.208	0.184	0.157
2.000	0.50	0.277	0.233	0.213	0.198	0.186	0.168	0.148	0.127
2.500	0.40	0.212	0.184	0.169	0.159	0.150	0.136	0.121	0.105
3.000	0.33	0.170	0.151	0.140	0.132	0.125	0.114	0.103	0.089
3.333	0.30	0.150	0.134	0.125	0.118	0.112	0.102	0.092	0.080
4.000	0.25	0.121	0.111	0.103	0.098	0.093	0.085	0.077	0.067
5.000	0.20	0.097	0.090	0.084	0.080	0.076	0.070	0.063	0.056
6.667	0.15	0.068	0.065	0.062	0.059	0.057	0.053	0.049	0.044
7.500	0.13	0.059	0.057	0.055	0.053	0.051	0.048	0.045	0.041
8.000	0.13	0.053	0.051	0.049	0.047	0.046	0.043	0.041	0.037
10.000	0.10	0.034	0.033	0.032	0.031	0.030	0.029	0.027	0.026

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Table 2-5. Horizontal Surface Soil SDC-3 Reduced Hazard Response Spectra for Different Damping Ratios at the LLNL Site

Period (sec)	Freq. (Hz)	Horizontal Spectral Acceleration (g)							
		0.5%	2%	3%	4%	5%	7%	10%	15%
PGA		0.570	0.571	0.571	0.571	0.571	0.571	0.570	0.570
0.010	100.00	0.572	0.573	0.573	0.573	0.573	0.572	0.572	0.572
0.011	90.00	0.575	0.574	0.574	0.573	0.573	0.572	0.572	0.571
0.013	80.00	0.578	0.575	0.575	0.574	0.573	0.573	0.572	0.571
0.014	70.00	0.582	0.577	0.576	0.575	0.574	0.573	0.572	0.570
0.017	60.00	0.587	0.580	0.578	0.577	0.575	0.574	0.572	0.570
0.020	50.00	0.593	0.584	0.581	0.579	0.578	0.576	0.574	0.571
0.022	45.00	0.611	0.591	0.586	0.582	0.580	0.576	0.573	0.570
0.025	40.00	0.632	0.600	0.592	0.587	0.583	0.578	0.573	0.570
0.029	35.00	0.658	0.612	0.601	0.594	0.589	0.581	0.575	0.570
0.033	30.00	0.707	0.635	0.619	0.608	0.600	0.589	0.579	0.570
0.040	25.00	0.782	0.673	0.648	0.632	0.620	0.604	0.588	0.572
0.050	20.00	0.901	0.738	0.702	0.678	0.661	0.637	0.614	0.590
0.067	15.00	1.167	0.908	0.848	0.808	0.778	0.739	0.699	0.658
0.075	13.33	1.314	1.003	0.929	0.881	0.844	0.796	0.748	0.697
0.080	12.50	1.397	1.063	0.983	0.930	0.889	0.836	0.782	0.724
0.100	10.00	1.704	1.286	1.178	1.106	1.050	0.975	0.898	0.816
0.111	9.00	1.894	1.421	1.298	1.214	1.150	1.063	0.974	0.879
0.125	8.00	2.135	1.592	1.448	1.351	1.276	1.173	1.068	0.957
0.143	7.00	2.437	1.806	1.636	1.520	1.430	1.308	1.182	1.049
0.150	6.67	2.520	1.863	1.685	1.563	1.469	1.340	1.208	1.069
0.167	6.00	2.559	1.894	1.708	1.581	1.483	1.347	1.208	1.061
0.200	5.00	2.657	1.969	1.768	1.630	1.524	1.374	1.221	1.059
0.250	4.00	2.630	1.968	1.768	1.628	1.517	1.368	1.212	1.046
0.300	3.33	2.530	1.941	1.750	1.615	1.510	1.358	1.201	1.034
0.333	3.000	2.509	1.936	1.746	1.611	1.506	1.353	1.196	1.027
0.400	2.50	2.256	1.758	1.587	1.464	1.367	1.227	1.082	0.927
0.500	2.00	1.947	1.540	1.394	1.288	1.205	1.083	0.956	0.819
0.667	1.50	1.587	1.277	1.158	1.071	1.002	0.898	0.791	0.675
0.750	1.33	1.490	1.208	1.096	1.013	0.948	0.850	0.748	0.637

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Period (sec)	Freq. (Hz)	Horizontal Spectral Acceleration (g)							
		0.5%	2%	3%	4%	5%	7%	10%	15%
0.800	1.25	1.408	1.149	1.045	0.968	0.907	0.814	0.717	0.612
1.000	1.00	1.113	0.934	0.856	0.796	0.750	0.676	0.600	0.515
1.111	0.90	0.978	0.823	0.755	0.703	0.662	0.598	0.531	0.457
1.250	0.80	0.840	0.708	0.650	0.606	0.571	0.517	0.459	0.396
1.429	0.70	0.704	0.595	0.547	0.511	0.481	0.436	0.388	0.335
1.500	0.67	0.648	0.549	0.505	0.471	0.444	0.403	0.359	0.310
1.667	0.60	0.538	0.459	0.423	0.396	0.374	0.340	0.304	0.264
2.000	0.50	0.391	0.338	0.314	0.295	0.280	0.255	0.229	0.200
2.500	0.40	0.283	0.248	0.231	0.217	0.207	0.190	0.172	0.152
3.000	0.33	0.217	0.192	0.179	0.170	0.162	0.149	0.136	0.121
3.333	0.30	0.186	0.165	0.155	0.146	0.140	0.129	0.118	0.105
4.000	0.25	0.146	0.131	0.124	0.117	0.112	0.104	0.095	0.085
5.000	0.20	0.115	0.107	0.101	0.096	0.093	0.086	0.079	0.071
6.667	0.15	0.088	0.081	0.077	0.073	0.071	0.066	0.061	0.055
7.500	0.13	0.078	0.072	0.068	0.065	0.063	0.059	0.054	0.049
8.000	0.13	0.069	0.064	0.061	0.059	0.057	0.053	0.049	0.045
10.000	0.10	0.046	0.044	0.043	0.041	0.040	0.038	0.036	0.033

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Table 2-6. Vertical Surface Soil SDC-3 Reduced Hazard Response Spectra for Different Damping Ratios at the LLNL Site

Period (sec)	Freq. (Hz)	Vertical Spectral Acceleration (g)							
		0.5%	2%	3%	4%	5%	7%	10%	15%
PGA		0.439	0.440	0.440	0.440	0.440	0.440	0.439	0.439
0.010	100.00	0.442	0.442	0.442	0.442	0.442	0.442	0.442	0.442
0.011	90.00	0.446	0.445	0.445	0.444	0.444	0.444	0.443	0.443
0.013	80.00	0.450	0.448	0.447	0.447	0.446	0.446	0.445	0.444
0.014	70.00	0.456	0.452	0.451	0.450	0.450	0.449	0.448	0.447
0.017	60.00	0.463	0.457	0.456	0.455	0.454	0.452	0.451	0.450
0.020	50.00	0.481	0.474	0.471	0.470	0.469	0.467	0.465	0.463
0.022	45.00	0.522	0.505	0.501	0.498	0.496	0.493	0.490	0.486
0.025	40.00	0.583	0.553	0.546	0.542	0.538	0.533	0.529	0.524
0.029	35.00	0.658	0.612	0.602	0.594	0.590	0.582	0.575	0.568
0.033	30.00	0.808	0.727	0.708	0.695	0.687	0.674	0.662	0.650
0.040	25.00	1.038	0.893	0.860	0.839	0.823	0.801	0.781	0.760
0.050	20.00	1.349	1.106	1.050	1.015	0.989	0.953	0.919	0.884
0.067	15.00	1.718	1.336	1.247	1.189	1.145	1.087	1.028	0.968
0.075	13.33	1.874	1.430	1.326	1.257	1.205	1.136	1.067	0.994
0.080	12.50	1.900	1.446	1.337	1.265	1.209	1.137	1.063	0.985
0.100	10.00	1.849	1.395	1.279	1.201	1.140	1.059	0.975	0.886
0.111	9.00	1.808	1.356	1.239	1.159	1.098	1.015	0.930	0.839
0.125	8.00	1.739	1.297	1.180	1.101	1.039	0.956	0.870	0.779
0.143	7.00	1.610	1.193	1.081	1.004	0.945	0.864	0.781	0.693
0.150	6.67	1.549	1.145	1.035	0.961	0.903	0.824	0.743	0.657
0.167	6.00	1.431	1.059	0.955	0.884	0.830	0.754	0.676	0.594
0.200	5.00	1.276	0.945	0.849	0.783	0.732	0.660	0.586	0.509
0.250	4.00	1.109	0.830	0.745	0.686	0.639	0.577	0.511	0.441
0.300	3.33	0.965	0.740	0.668	0.616	0.576	0.518	0.458	0.395
0.333	3.000	0.912	0.703	0.635	0.585	0.547	0.492	0.435	0.373
0.400	2.50	0.777	0.606	0.547	0.504	0.471	0.423	0.373	0.319
0.500	2.00	0.636	0.503	0.456	0.421	0.394	0.354	0.312	0.268
0.667	1.50	0.515	0.415	0.376	0.348	0.325	0.292	0.257	0.219
0.750	1.33	0.487	0.394	0.358	0.331	0.310	0.277	0.244	0.208

Period (sec)	Freq. (Hz)	Vertical Spectral Acceleration (g)							
		0.5%	2%	3%	4%	5%	7%	10%	15%
0.800	1.25	0.464	0.379	0.345	0.319	0.299	0.268	0.237	0.202
1.000	1.00	0.381	0.320	0.293	0.273	0.257	0.232	0.205	0.176
1.111	0.90	0.339	0.285	0.262	0.244	0.230	0.208	0.184	0.158
1.250	0.80	0.294	0.248	0.228	0.212	0.200	0.181	0.161	0.139
1.429	0.70	0.249	0.211	0.194	0.181	0.170	0.155	0.138	0.119
1.500	0.67	0.232	0.197	0.181	0.169	0.159	0.144	0.129	0.111
1.667	0.60	0.200	0.171	0.158	0.147	0.139	0.127	0.113	0.098
2.000	0.50	0.157	0.136	0.126	0.118	0.112	0.102	0.092	0.080
2.500	0.40	0.122	0.106	0.099	0.093	0.089	0.082	0.074	0.065
3.000	0.33	0.099	0.087	0.082	0.077	0.074	0.068	0.062	0.055
3.333	0.30	0.088	0.078	0.073	0.069	0.066	0.061	0.056	0.049
4.000	0.25	0.072	0.065	0.061	0.058	0.056	0.052	0.047	0.042
5.000	0.20	0.059	0.054	0.051	0.049	0.047	0.044	0.040	0.036
6.667	0.15	0.044	0.040	0.038	0.037	0.035	0.033	0.030	0.027
7.500	0.13	0.038	0.035	0.034	0.032	0.031	0.029	0.027	0.024
8.000	0.13	0.034	0.032	0.030	0.029	0.028	0.026	0.024	0.022
10.000	0.10	0.023	0.022	0.021	0.020	0.020	0.019	0.017	0.016

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Table 2-7. Horizontal Surface Soil SDC-3 Response Spectra for Different Damping Ratios at the LLNL Site

Period (sec)	Freq. (Hz)	Horizontal Spectral Acceleration (g)							
		0.5%	2%	3%	4%	5%	7%	10%	15%
PGA		0.673	0.673	0.673	0.673	0.673	0.673	0.673	0.672
0.010	100.00	0.675	0.676	0.676	0.676	0.676	0.675	0.675	0.675
0.011	90.00	0.678	0.677	0.677	0.676	0.676	0.675	0.675	0.674
0.013	80.00	0.682	0.679	0.678	0.677	0.676	0.676	0.675	0.673
0.014	70.00	0.686	0.681	0.679	0.678	0.677	0.676	0.674	0.673
0.017	60.00	0.692	0.684	0.681	0.680	0.678	0.677	0.675	0.672
0.020	50.00	0.699	0.688	0.685	0.683	0.681	0.678	0.676	0.673
0.022	45.00	0.720	0.696	0.690	0.686	0.683	0.679	0.675	0.672
0.025	40.00	0.744	0.707	0.697	0.691	0.687	0.681	0.675	0.672
0.029	35.00	0.774	0.720	0.707	0.699	0.693	0.684	0.676	0.672
0.033	30.00	0.833	0.749	0.729	0.716	0.707	0.694	0.682	0.672
0.040	25.00	0.924	0.795	0.765	0.746	0.732	0.713	0.695	0.676
0.050	20.00	1.059	0.868	0.825	0.797	0.777	0.748	0.721	0.694
0.067	15.00	1.345	1.047	0.977	0.931	0.897	0.851	0.806	0.758
0.075	13.33	1.509	1.152	1.067	1.012	0.970	0.915	0.859	0.800
0.080	12.50	1.610	1.225	1.133	1.072	1.025	0.963	0.900	0.835
0.100	10.00	1.988	1.500	1.374	1.290	1.225	1.138	1.048	0.952
0.111	9.00	2.207	1.656	1.512	1.415	1.340	1.239	1.135	1.024
0.125	8.00	2.488	1.856	1.688	1.575	1.487	1.367	1.245	1.115
0.143	7.00	2.861	2.120	1.920	1.784	1.679	1.535	1.387	1.231
0.150	6.67	2.980	2.203	1.992	1.849	1.738	1.585	1.429	1.264
0.167	6.00	3.072	2.273	2.051	1.898	1.781	1.617	1.451	1.274
0.200	5.00	3.159	2.341	2.103	1.939	1.812	1.634	1.452	1.259
0.250	4.00	3.140	2.350	2.111	1.945	1.811	1.633	1.447	1.249
0.300	3.33	3.034	2.327	2.098	1.936	1.810	1.628	1.440	1.240
0.333	3.000	3.030	2.338	2.109	1.945	1.818	1.634	1.444	1.241
0.400	2.50	2.804	2.186	1.973	1.820	1.700	1.526	1.345	1.152
0.500	2.00	2.434	1.925	1.742	1.610	1.506	1.353	1.195	1.023
0.667	1.50	1.984	1.596	1.448	1.338	1.252	1.123	0.989	0.844
0.750	1.33	1.863	1.510	1.370	1.267	1.186	1.062	0.935	0.796

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Period (sec)	Freq. (Hz)	Horizontal Spectral Acceleration (g)							
		0.5%	2%	3%	4%	5%	7%	10%	15%
0.800	1.25	1.759	1.437	1.307	1.210	1.134	1.018	0.897	0.765
1.000	1.00	1.391	1.167	1.069	0.995	0.937	0.845	0.749	0.644
1.111	0.90	1.223	1.028	0.943	0.879	0.827	0.747	0.664	0.571
1.250	0.80	1.050	0.885	0.813	0.758	0.714	0.646	0.574	0.495
1.429	0.70	0.880	0.744	0.684	0.638	0.601	0.545	0.485	0.419
1.500	0.67	0.810	0.686	0.631	0.589	0.555	0.504	0.449	0.388
1.667	0.60	0.673	0.574	0.529	0.495	0.468	0.425	0.380	0.330
2.000	0.50	0.489	0.423	0.392	0.368	0.350	0.319	0.287	0.250
2.500	0.40	0.354	0.309	0.288	0.272	0.259	0.238	0.215	0.189
3.000	0.33	0.271	0.239	0.224	0.212	0.202	0.187	0.170	0.151
3.333	0.30	0.232	0.206	0.193	0.183	0.175	0.162	0.147	0.131
4.000	0.25	0.182	0.164	0.154	0.147	0.140	0.130	0.119	0.106
5.000	0.20	0.144	0.133	0.126	0.120	0.116	0.108	0.099	0.088
6.667	0.15	0.109	0.101	0.096	0.092	0.088	0.082	0.076	0.068
7.500	0.13	0.097	0.090	0.085	0.081	0.078	0.073	0.068	0.061
8.000	0.13	0.086	0.080	0.077	0.073	0.071	0.066	0.061	0.056
10.000	0.10	0.057	0.055	0.053	0.052	0.050	0.048	0.045	0.041

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Table 2-8. Vertical Surface Soil SDC-3 Response Spectra for Different Damping Ratios at the LLNL Site

Period (sec)	Freq. (Hz)	Vertical Spectral Acceleration (g)							
		0.5%	2%	3%	4%	5%	7%	10%	15%
PGA		0.548	0.548	0.548	0.548	0.548	0.548	0.548	0.548
0.010	100.00	0.551	0.551	0.551	0.551	0.551	0.551	0.551	0.551
0.011	90.00	0.556	0.555	0.555	0.555	0.554	0.554	0.553	0.553
0.013	80.00	0.562	0.560	0.559	0.558	0.558	0.557	0.556	0.555
0.014	70.00	0.570	0.565	0.564	0.563	0.562	0.561	0.560	0.558
0.017	60.00	0.578	0.572	0.570	0.568	0.567	0.566	0.564	0.562
0.020	50.00	0.602	0.592	0.589	0.587	0.586	0.584	0.582	0.579
0.022	45.00	0.653	0.631	0.626	0.622	0.620	0.616	0.612	0.608
0.025	40.00	0.729	0.692	0.683	0.677	0.673	0.667	0.661	0.655
0.029	35.00	0.823	0.766	0.752	0.743	0.737	0.728	0.719	0.710
0.033	30.00	1.010	0.908	0.885	0.869	0.858	0.842	0.827	0.812
0.040	25.00	1.298	1.116	1.075	1.048	1.029	1.002	0.976	0.950
0.050	20.00	1.686	1.382	1.313	1.269	1.237	1.192	1.149	1.105
0.067	15.00	2.147	1.670	1.559	1.486	1.431	1.358	1.285	1.210
0.075	13.33	2.343	1.788	1.657	1.572	1.506	1.420	1.333	1.243
0.080	12.50	2.374	1.807	1.671	1.581	1.511	1.421	1.328	1.231
0.100	10.00	2.312	1.744	1.598	1.501	1.425	1.323	1.219	1.108
0.111	9.00	2.259	1.695	1.548	1.449	1.372	1.269	1.162	1.049
0.125	8.00	2.174	1.621	1.475	1.376	1.299	1.195	1.088	0.974
0.143	7.00	2.013	1.492	1.351	1.255	1.181	1.080	0.976	0.866
0.150	6.67	1.936	1.431	1.294	1.201	1.129	1.030	0.928	0.821
0.167	6.00	1.789	1.324	1.194	1.105	1.037	0.942	0.845	0.742
0.200	5.00	1.595	1.182	1.061	0.978	0.915	0.825	0.733	0.636
0.250	4.00	1.386	1.037	0.932	0.858	0.799	0.721	0.638	0.551
0.300	3.33	1.207	0.926	0.835	0.770	0.720	0.647	0.573	0.493
0.333	3.000	1.140	0.879	0.793	0.732	0.684	0.615	0.543	0.467
0.400	2.50	0.971	0.757	0.683	0.630	0.589	0.528	0.466	0.399
0.500	2.00	0.795	0.629	0.569	0.526	0.492	0.442	0.390	0.334
0.667	1.50	0.644	0.518	0.470	0.435	0.407	0.365	0.321	0.274
0.750	1.33	0.608	0.493	0.447	0.414	0.387	0.347	0.305	0.260

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Period (sec)	Freq. (Hz)	Vertical Spectral Acceleration (g)							
		0.5%	2%	3%	4%	5%	7%	10%	15%
0.800	1.25	0.580	0.474	0.431	0.399	0.374	0.336	0.296	0.252
1.000	1.00	0.476	0.400	0.366	0.341	0.321	0.290	0.257	0.220
1.111	0.90	0.424	0.357	0.327	0.305	0.287	0.259	0.230	0.198
1.250	0.80	0.368	0.310	0.285	0.266	0.250	0.226	0.201	0.173
1.429	0.70	0.312	0.264	0.242	0.226	0.213	0.193	0.172	0.149
1.500	0.67	0.290	0.246	0.226	0.211	0.199	0.180	0.161	0.139
1.667	0.60	0.250	0.214	0.197	0.184	0.174	0.158	0.142	0.123
2.000	0.50	0.196	0.169	0.157	0.148	0.140	0.128	0.115	0.100
2.500	0.40	0.152	0.133	0.124	0.117	0.111	0.102	0.092	0.081
3.000	0.33	0.124	0.109	0.102	0.097	0.092	0.085	0.077	0.069
3.333	0.30	0.109	0.097	0.091	0.086	0.083	0.076	0.070	0.062
4.000	0.25	0.090	0.081	0.077	0.073	0.070	0.065	0.059	0.053
5.000	0.20	0.073	0.068	0.064	0.061	0.059	0.055	0.050	0.045
6.667	0.15	0.055	0.050	0.048	0.046	0.044	0.041	0.038	0.034
7.500	0.13	0.048	0.044	0.042	0.040	0.039	0.036	0.033	0.030
8.000	0.13	0.043	0.040	0.038	0.036	0.035	0.033	0.030	0.027
10.000	0.10	0.028	0.027	0.026	0.025	0.025	0.023	0.022	0.020

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FIGURES

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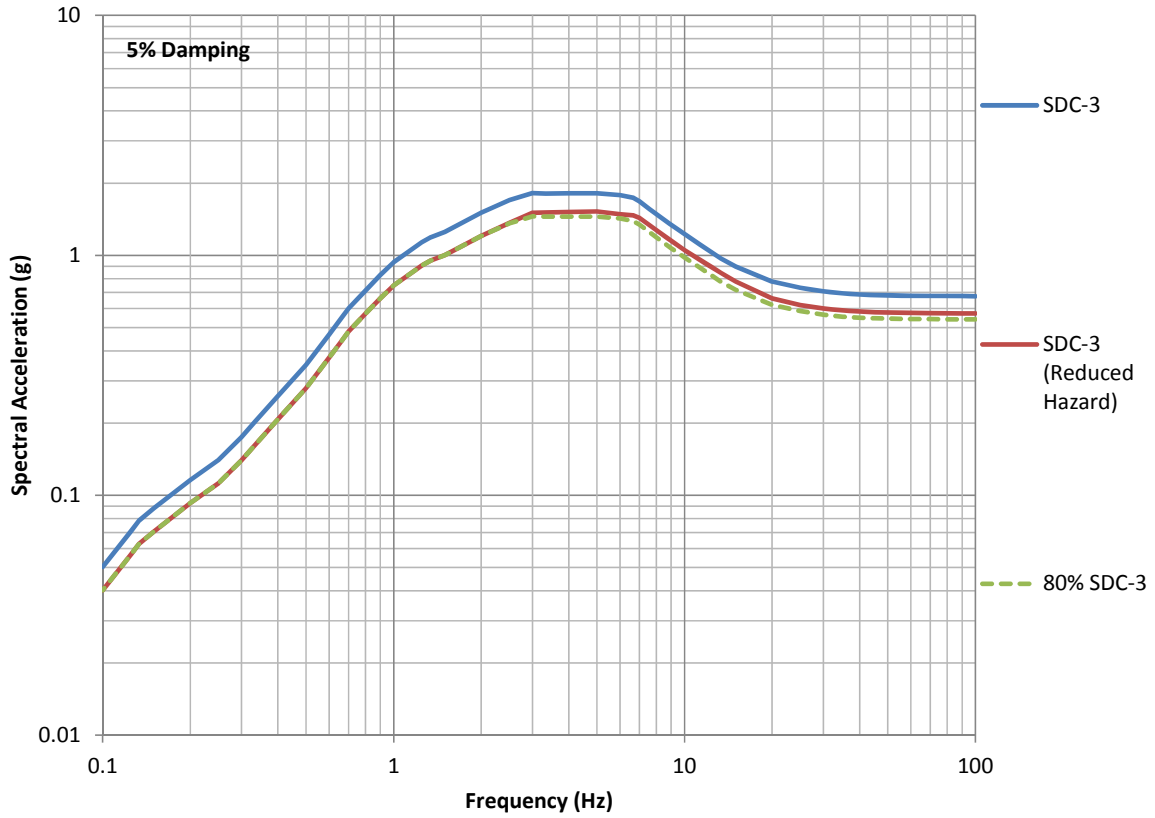

Figure 2-1. Comparison of Horizontal SDC-3 Reduced Hazard, 80% of SDC-3 and SDC-3 Response Spectra for a 5% Damping at the LLNL Site

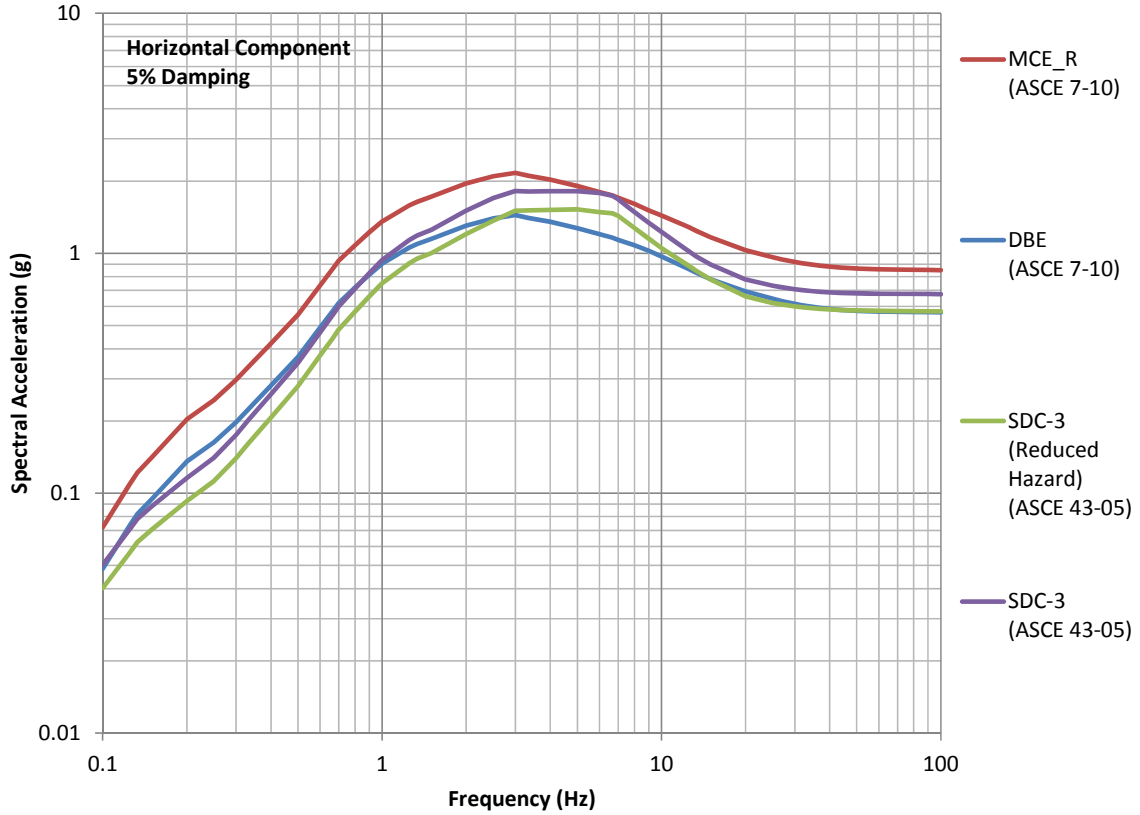

Figure 2-2. Comparison of Horizontal ASCE 7-10 DBE, ASCE 7-10 MCE_R, SDC-3 Reduced Hazard, and SDC-3 Response Spectra for a 5% Damping at the LLNL Site

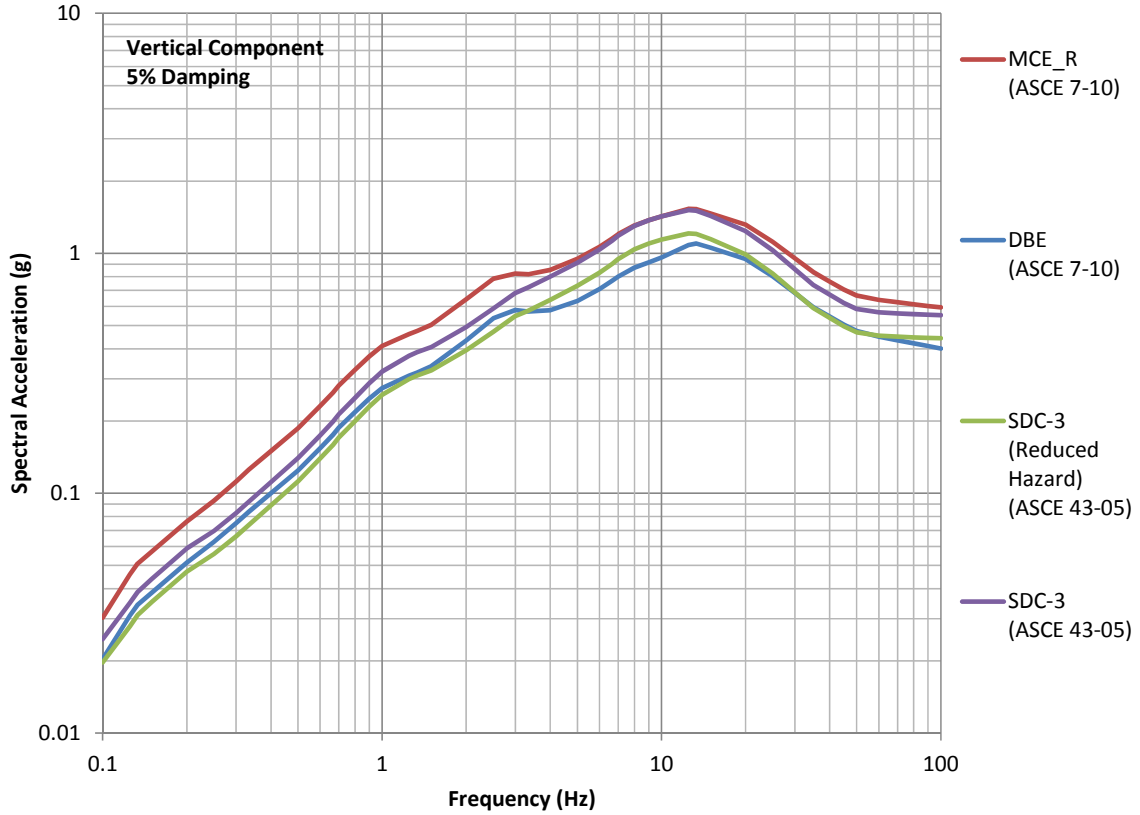

Figure 2-3. Comparison of Vertical ASCE 7-10 DBE, ASCE 7-10 MCE_R, SDC-3 Reduced Hazard, and SDC-3 Response Spectra for a 5% Damping at the LLNL Site