From: "Spears, Annie Rebecca" <ARSPEARS@southernco.com>
To: "Mark Notich" <mdn@nrc.gov>
Date: 6/15/2007 8:38:13 AM
Subject: FW: AR-07-1162_Final

Mark,

Attached is AR-07-1162 Enclosure - Supplemental Response to Geology/Seismology RAIs for Vogtle ESP Application.
The original letter went out yesterday on Fedex.

Thanks!
Annie Spears
SNC - Nuclear Development
Internal 8-992-7024
External Phone #: 205-992-7024

<<AR-07-1162_Final.pdf>>

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From: "Spears, Annie Rebecca" <ARSPEARS@southernco.com>

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Recipients
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Security:	Standard

J. A. "Buzz" Miller
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SOUTHERN COMPANY
Energy to Serve Your World℠

JUN 14 2007

Docket No.: 52-011 AR-07-1162

U.S. Nuclear Regulatory Commission
Document Control Desk
Washington, DC 20555-0001

Southern Nuclear Operating Company
Vogtle Early Site Permit Application
Supplemental Response to Requests for Additional Information on Geology/Seismology

Ladies and Gentlemen:

By letter dated March 15, 2007, the U.S. Nuclear Regulatory Commission (NRC) provided Southern Nuclear Operating Company (SNC) with Request for Additional Information (RAI) Letter No. 6 on the Vogtle Early Site Permit (ESP) Application. The RAIs in that letter pertain to ESP application Part 2, Site Safety Analysis Report (SSAR), Section 2.4, *Hydrologic Engineering*, and Section 2.5, *Geology, Seismology and Geotechnical Engineering*. SNC's response to the RAIs pertaining to SSAR Section 2.5 was provided to the NRC in submittal letter AR-07-0801, dated April 16, 2007. Based on subsequent discussions with the NRC regarding SNC's response to the SSAR Section 2.5 RAIs, the NRC has requested SNC to supplement its responses for selected RAIs. The supplemental response is based on agreements reached between the NRC and SNC on a teleconference call held on May 17, 2008, and is provided in the enclosure to this letter.

If you have any questions or require additional information regarding this matter, please contact J. T. Davis at (205) 992-7692.

Mr. J. A. (Buzz) Miller states he is a Senior Vice President of Southern Nuclear Operating Company, is authorized to execute this oath on behalf of Southern Nuclear Operating Company and to the best of his knowledge and belief, the facts set forth in this letter are true.

Respectfully submitted,

SOUTHERN NUCLEAR OPERATING COMPANY

JA Miller

Joseph A. (Buzz) Miller

Sworn to and subscripted before me this 14 *day of* June, *2007*

Gloria H. Buie

Notary Public

My commission expires: 05/06/08

JAM/BJS/dmw

Enclosure: Supplemental Response to Geology/Seismology RAIs on the Vogtle ESP Application

cc: Southern Nuclear Operating Company
Mr. J. B. Beasley, Jr., President and CEO (w/o enclosure)
Mr. J. T. Gasser, Executive Vice President, Nuclear Operations (w/o enclosure)
Mr. T. E. Tynan, Vice President - Vogtle (w/o enclosure)
Mr. D. M. Lloyd, Vogtle Deployment Director (w/o enclosure)
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Document Services RTYPE: AR01
File AR.01.01.06

Nuclear Regulatory Commission
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Mr. D. B. Matthews, Director of New Reactors (w/o enclosure)
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Bechtel Power Corporation
Mr. J. S. Prebula, Project Engineer (w/o enclosure)
Mr. R. W. Prunty, Licensing Engineer

Southern Nuclear Operating Company

AR-07-1162

Enclosure

Supplemental Response to Geology/Seismology RAIs on the Vogtle ESP Application

SSAR Section 2.5.1 Basic Geologic and Seismic Information

2.5.1-17 To supplement discussion of the fluvial terrace investigation, please describe results of the various other morphometric analyses also conducted by Geomatrix (1993) leading to the conclusion that morphometric signatures which could be related to either long-term tectonic effects or non-tectonic factors likewise indicate the Pen Branch Fault is not a capable tectonic structure.

Discuss in particular results of the drainage basin studies performed by Geomatrix (1993) since Hanson et al (1993) stated these studies suggested rejuvenation of stream drainage patterns along the trace of the Pen Branch Fault. Based on data from Geomatrix (1993) indicating [1] longitudinal profiles of fluvial terrace surfaces show no evidence of obvious warping within a resolution limit of about 3m and [2] the estimated age of terrace surfaces is 350ka to 1Ma, Hanson et al (1993) also stated that the Pleistocene slip rate for the Pen Branch Fault, if it is active, is very low (i.e., 0.002 to 0.009 mm/yr).

Response:

Geomatrix Consultants received funding from the U.S. Department of Energy (DOE) to perform neotectonic and morphometric analyses of the Savannah River Site (SRS). The results and implications of these analyses are described in two reports:

1. Geomatrix (February, 1993). This 168-page report prepared for Lawrence Livermore National Laboratory and Westinghouse Savannah River Company describes data collection and interpretation related to the Quaternary and Neotectonic Program for the SRS. In addition to quantitative morphometric analyses, this report includes results from Quaternary mapping, age estimates of Quaternary deposits and surfaces, evaluation of previously mapped small-scale deformation features at the SRS, documentation of the lack of paleoliquefaction features encountered at the SRS, and integration of existing borehole and seismic reflection data.
2. Hanson et al. (October, 1993). This 10-page summary report prepared for the Fourth DOE Natural Phenomena Hazards Mitigation Conference presents a brief summary of the data and interpretations published eight months earlier in Geomatrix (1993).

Geomorphic analyses performed as part of the Geomatrix SRS Quaternary and Neotectonic study include:

- Construction of a regional slope map and slope profiles
- Construction of longitudinal stream profiles and calculation of stream-gradient (SL) indices
- Construction of topographic envelope-subenvelope residual maps
- Evaluation of drainage basin shape and elongation
- Calculation of drainage density and drainage frequency
- Construction of fluvial terrace surface profiles

The results of each of these analyses are described below.

The regional slope map of the SRS site area suggests a lack of recent tectonic deformation at the SRS. The Geomatrix regional slope analysis shows that "[n]o obvious topographic deviations are expressed on the profiles that would be associated with the known geologic structures in the site area" (Geomatrix 1993, p. 42). Some minor topographic highs are evident in the vicinity of the Pen Branch fault, but "no consistent topographic anomalies are associated with [the Pen Branch fault] or other structures in the site area" (Geomatrix 1993, p. 42).

Longitudinal stream profiles and SL indices are relatively sensitive indicators of potential recent tectonic activity, and the Geomatrix analysis of these parameters suggests a lack of recent tectonic deformation at the SRS. Stream profile convexities and clusters of high SL index values appear to be distributed randomly along stream profiles and are interpreted as "likely the result of complex geomorphic responses that transport sediment through the system" (Geomatrix 1993, p. 43). Hanson et al. (1993) note possible convexities in stream profiles in the vicinity of the Pen Branch fault that may be attributed to possible long-term tectonic effects; alternatively, "these features may derive entirely or in part from other [non-tectonic] geologic factors and geomorphic processes" (p. 677).

The Geomatrix envelope-subenvelope residual map analysis suggests a lack of tectonic deformation at the SRS. Envelope-subenvelope residuals are a proxy for spatial variation in long-term fluvial incision of a landscape. Geomatrix (1993) states that the "residual map analysis does not identify any clear structural features expressed in the landscape. Some alignments of larger residuals are weakly apparent but are not consistently associated with known geologic structures" (p. 45).

The quantitative analysis of SRS drainage basin shape and elongation suggests a lack of tectonic deformation at the SRS. Geomatrix (1993) concludes that assessment of basin morphometry "shows no consistency in the distribution of basin shape or elongation" (p. 46).

Geomatrix (1993) notes that contour maps of drainage density and drainage frequency show general regions of high values in the vicinity of the Pen Branch fault. These two parameters are closely related and largely measure the same phenomenon: drainage density is the total length of stream segments per unit area, whereas drainage frequency is the total number of stream segments per unit area. Hanson et al. (1993) suggest the possibility that the zone of high drainage density and frequency along the Pen Branch fault represents a broad zone of uplift and rejuvenation of tributary drainages along the trace of the Pen Branch fault. It is important to note, however, that the area of increased drainage density and frequency appears both north and south of the Pen Branch fault (i.e., on both the up- and down-thrown blocks of the fault).

It is likely that pre-Quaternary uplift and deformation on the Pen Branch fault influences modern drainage patterns, including drainage density and frequency. The influence of Tertiary and earlier tectonic deformation on SRS drainage patterns is evident in the location and cross-valley profiles of the Upper Three Runs drainage. The asymmetry of Upper Three Runs cross-valley is a result of fluvial erosion along a dip slope in the south-dipping Eocene McBean Formation, predominately a sandy limestone.

Savannah River Quaternary fluvial terrace surfaces represent the most-reliable strain markers with which to test for the possibility of tectonic deformation. Studies of SRS Quaternary fluvial terraces overlying the surface projection of the Pen Branch fault performed by Geomatrix (Geomatrix 1993; Hanson et al. 1993) demonstrate the lack of evidence for vertical tectonic deformation of the terrace surfaces within a resolution of 7 to 10 ft (2 to 3 m). A higher-resolution study performed for the Vogtle ESP application provides evidence demonstrating the absence of tectonic deformation within a resolution of about 3 ft (1 m) for the 350 ka to 1 Ma Ellenton (Qte) terrace surface. The results of these studies provide the most-reliable evidence demonstrating the lack of Quaternary deformation on the Pen Branch fault.

As a hypothetical exercise, Geomatrix (1993) and Hanson et al. (1993) calculate a maximum long-term average vertical separation rate for the Pen Branch fault of 0.002 to 0.009 mm/yr. This separation rate assumes that the Pen Branch fault is active and is based on a maximum displacement of 2 to 3 m for the 350 ka to 1 Ma Qte surface. Using the 1 m displacement limit provided by the higher-resolution terrace study performed for the Vogtle ESP application, the hypothetical vertical separation rate for the Pen

Branch fault (assuming it is active) decreases to 0.001 to 0.003 mm/yr. These hypothetical rates are very low and based on the unsupported assumption that the Pen Branch fault is active.

In summary, the preponderance of geomorphic evidence from the SRS suggests that the Pen Branch fault is not a capable tectonic feature. The SRS fluvial terrace study performed for the Vogtle ESP application provides the most definitive evidence demonstrating the absence of tectonic deformation within a resolution of about 3 ft (1 m). This provides a much smaller deformation detection limit than previous studies, thereby providing greater confidence in the evidence demonstrating the lack of Quaternary deformation on the Pen Branch fault.

References

(Geomatrix 1993) Geomatrix Consultants Inc., Preliminary Quaternary and neotectonic studies - Savannah River Site, South Carolina: report prepared for Lawrence Livermore National Laboratory and Westinghouse Savannah River Company, 1993.

(Hanson et al. 1993) Hanson, K.L., Bullard, T.F., de Wit, M.W., and Stieve, A.L., Applications of Quaternary stratigraphic, soil-geomorphic, and quantitative geomorphic analyses to the evaluation of tectonic activity and landscape evolution in the upper coastal plain, South Carolina: 4th D.O.E. Natural Phenomena Hazards Mitigation Conference Proceedings, v. 2, p. 672-681, 1993.

SSAR Section 2.5.2 Vibratory Ground Motion

2.5.2-3 In response to this RAI, soil hazard curves were provided at three annual exceedence frequencies (10^{-4}, 10^{-5}, and 10^{-6}). However, in order for the staff to verify the adequacy of the SSE, soil hazard curves are requested at additional annual exceedence frequencies (i.e. at values between 10^{-4}, 10^{-5}, and 10^{-6}).

Response:

Soil ground motion values for annual probability of exceedence levels of 10^{-4}, 10^{-5}, and 10^{-6} were provided in the original response to the RAI. An additional request has been made to provide the soil hazard curves at a suite of points in addition to the three points originally provided.

Spectral acceleration ground motion values are given in SSAR Table 2.5.2-21 of the Vogtle ESP application for both hard rock and top of Blue Bluff Marl outcrop soil site conditions. These values for the seven frequencies at which the PSHA was performed are listed below in Table 1 along with the Soil/Hard Rock spectral ratio for each of the three annual probability levels.

Table 1. Hard rock, top of Blue Bluff Marl outcrop and resulting spectral ratio of resulting ground motion values.

	Hard Rock			**Top of Blue Bluff Marl**			**Spectral Ratio**		
Freq. (Hz)	**SA (g) 10^{-4}**	**SA (g) 10^{-5}**	**SA (g) 10^{-6}**	**SA (g) 10^{-4}**	**SA (g) 10^{-5}**	**SA (g) 10^{-6}**	**Ratio 10^{-4}**	**Ratio 10^{-5}**	**Ratio 10^{-6}**
100	0.214	0.559	1.480	0.255	0.531	1.025	1.192	0.950	0.693
25	0.551	1.540	4.090	0.646	1.217	1.636	1.173	0.790	0.400
10	0.399	0.983	2.330	0.722	1.522	2.405	1.810	1.548	1.032
5	0.317	0.728	1.540	0.612	1.306	2.665	1.930	1.793	1.731
2.5	0.223	0.512	1.020	0.706	1.300	2.184	3.167	2.538	2.142
1	0.101	0.235	0.465	0.226	0.597	1.396	2.236	2.542	3.002
0.5	0.065	0.185	0.423	0.238	0.745	1.741	3.643	4.027	4.117

For each of the seven frequencies a quadratic equation was fit to the log (base10) of the spectral ratios (AMP) as a function of the log (base10) of the annual exceedence probability (AEP). Mathematically, this functional model is given as,

$$\mathrm{Log}_{10}\,(\mathrm{AMP}) = C_1 + C_2{*}\mathrm{Log}_{10}\,(\mathrm{AEP}) + C_3{*}[\mathrm{Log}_{10}(\mathrm{AEP})]^2 \qquad (1)$$

The resulting fits to the three data points are shown in Figure 1, located on the following pages, for each of the seven frequencies. The coefficients and equation are given at the top of each plot. Note that the red dashed line is a linear log-log line between the three data points.

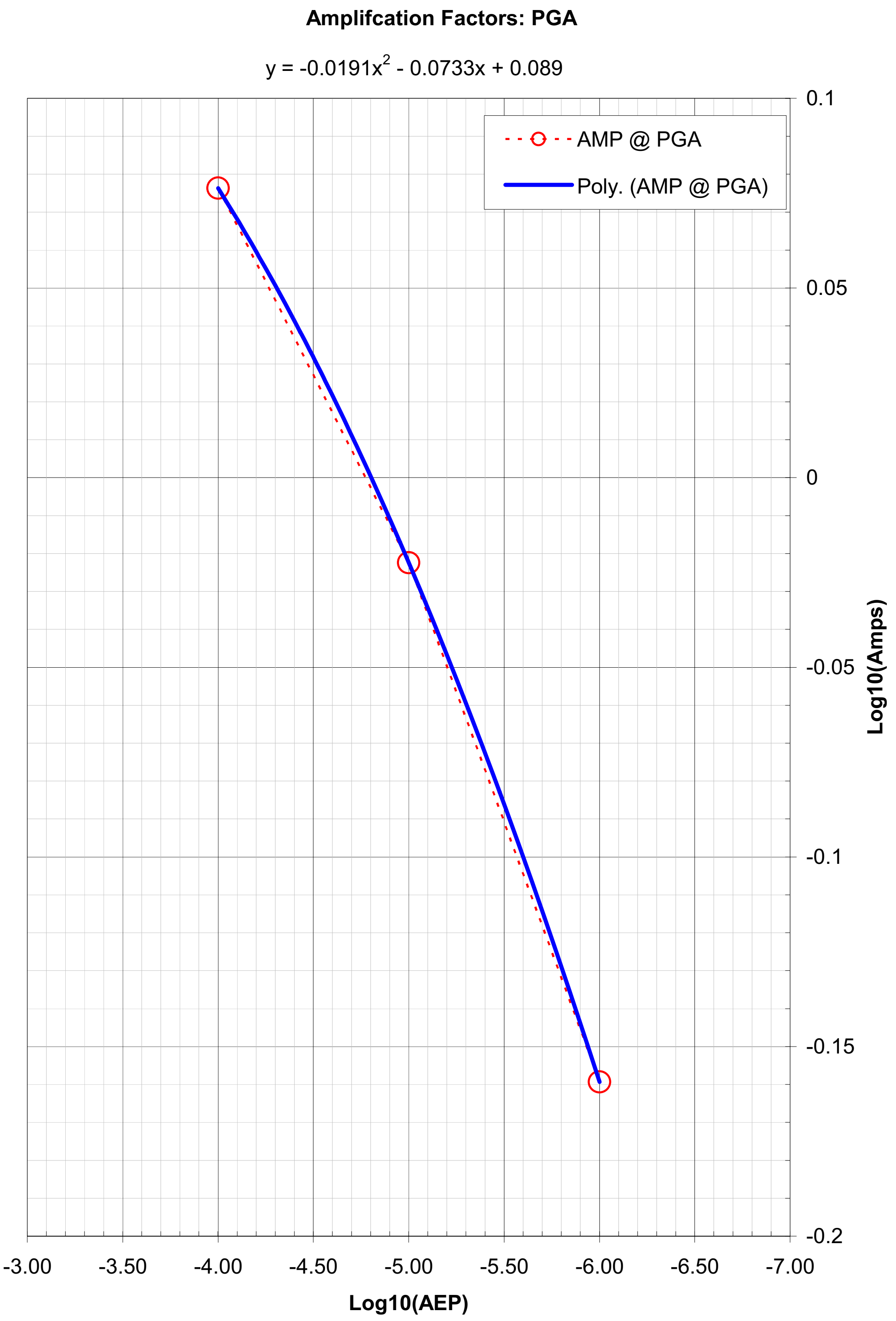


Figure 1a. Quadratic fit to the amplification values for 100 Hz.

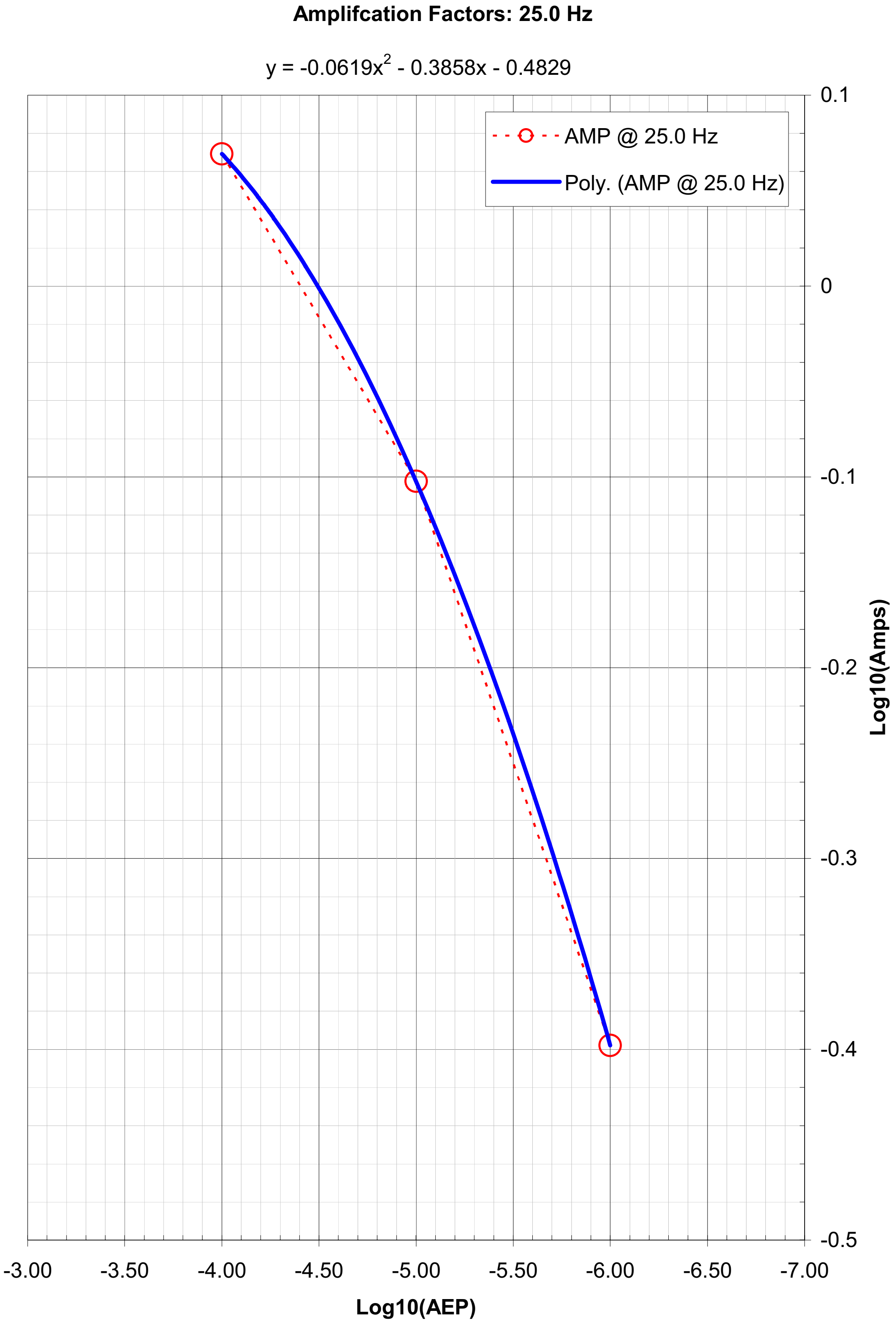


Figure 1b. Quadratic fit to the amplification values for 25 Hz.

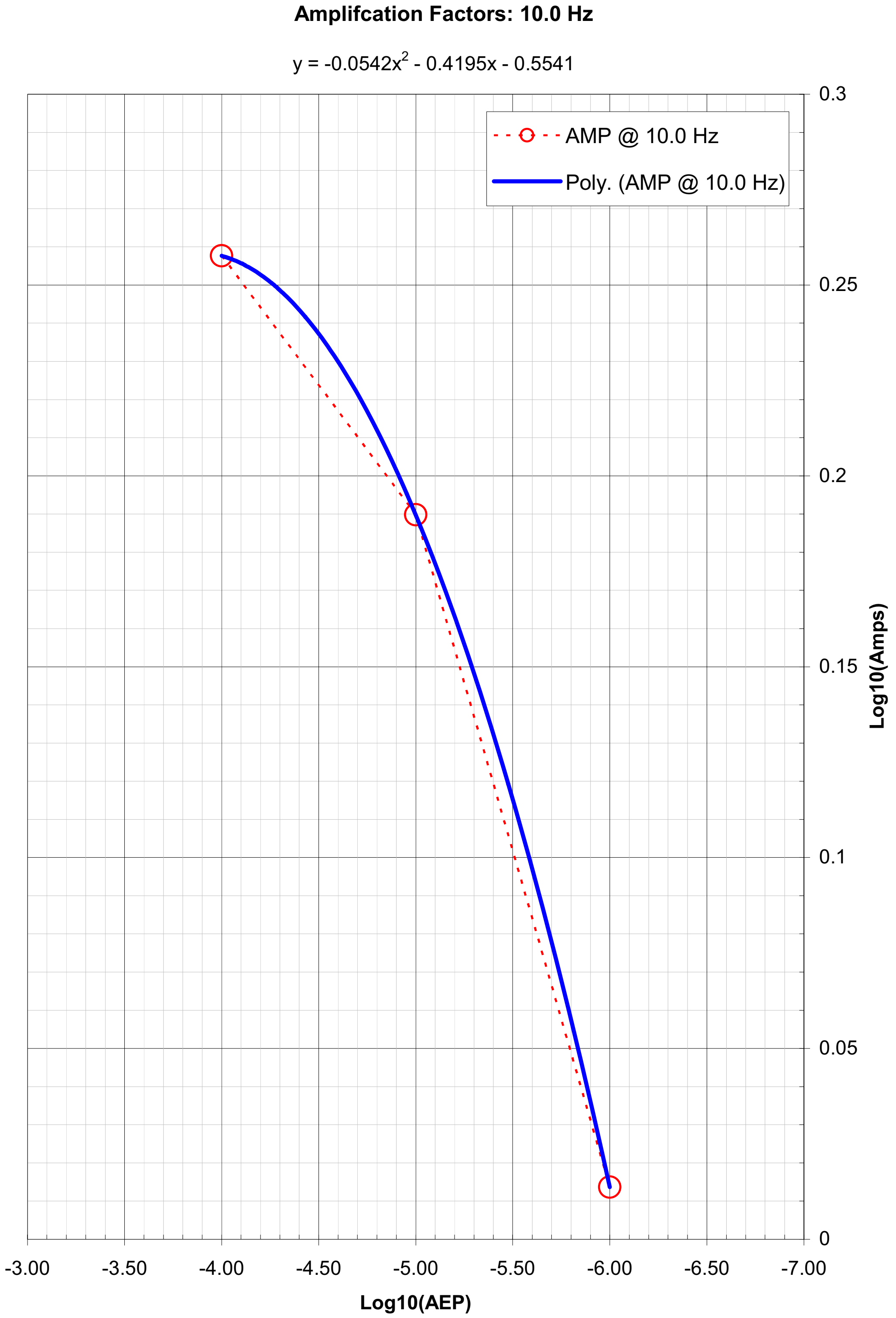


Figure 1c. Quadratic fit to the amplification values for 10 Hz.

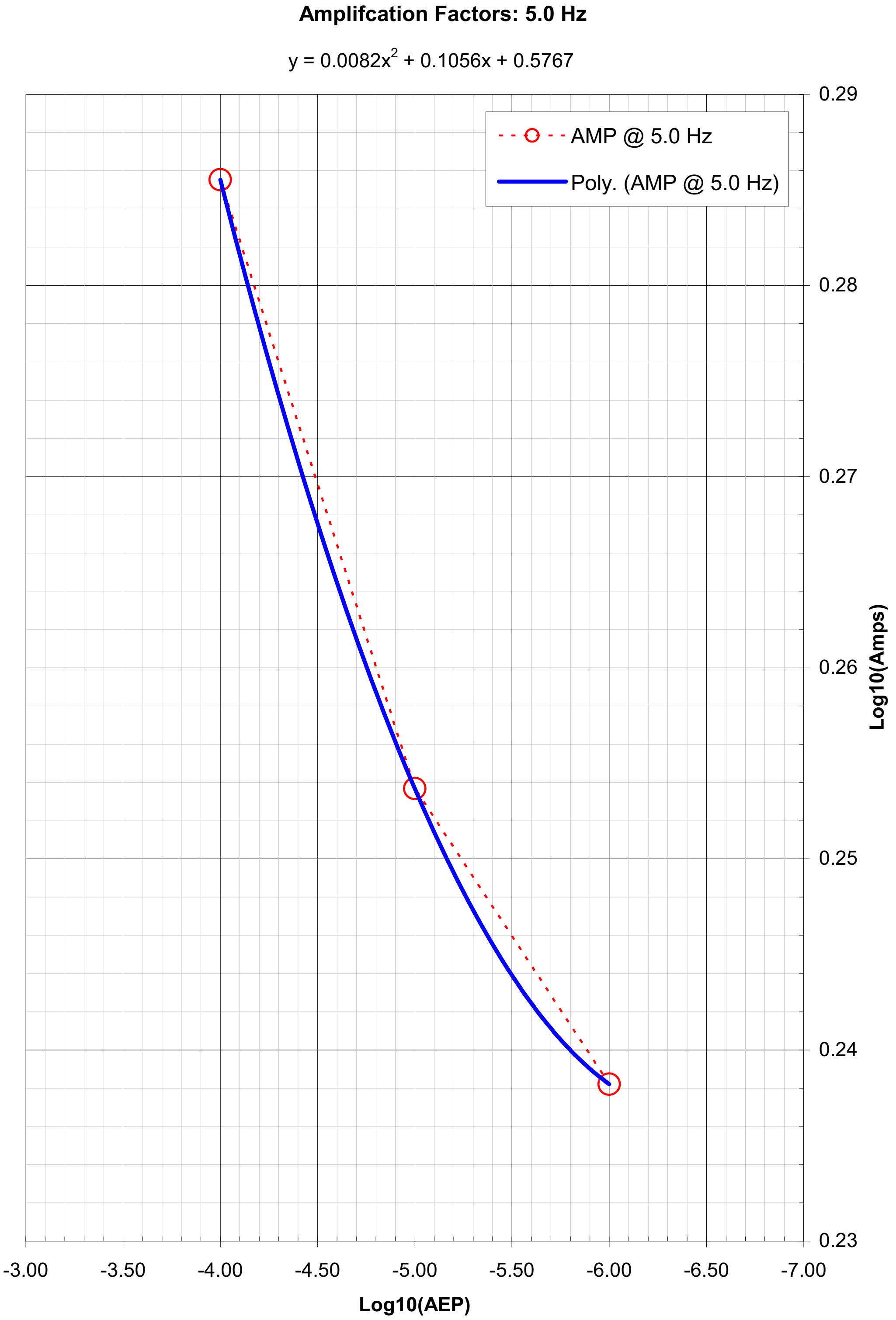


Figure 1d. Quadratic fit to the amplification values for 5 Hz.

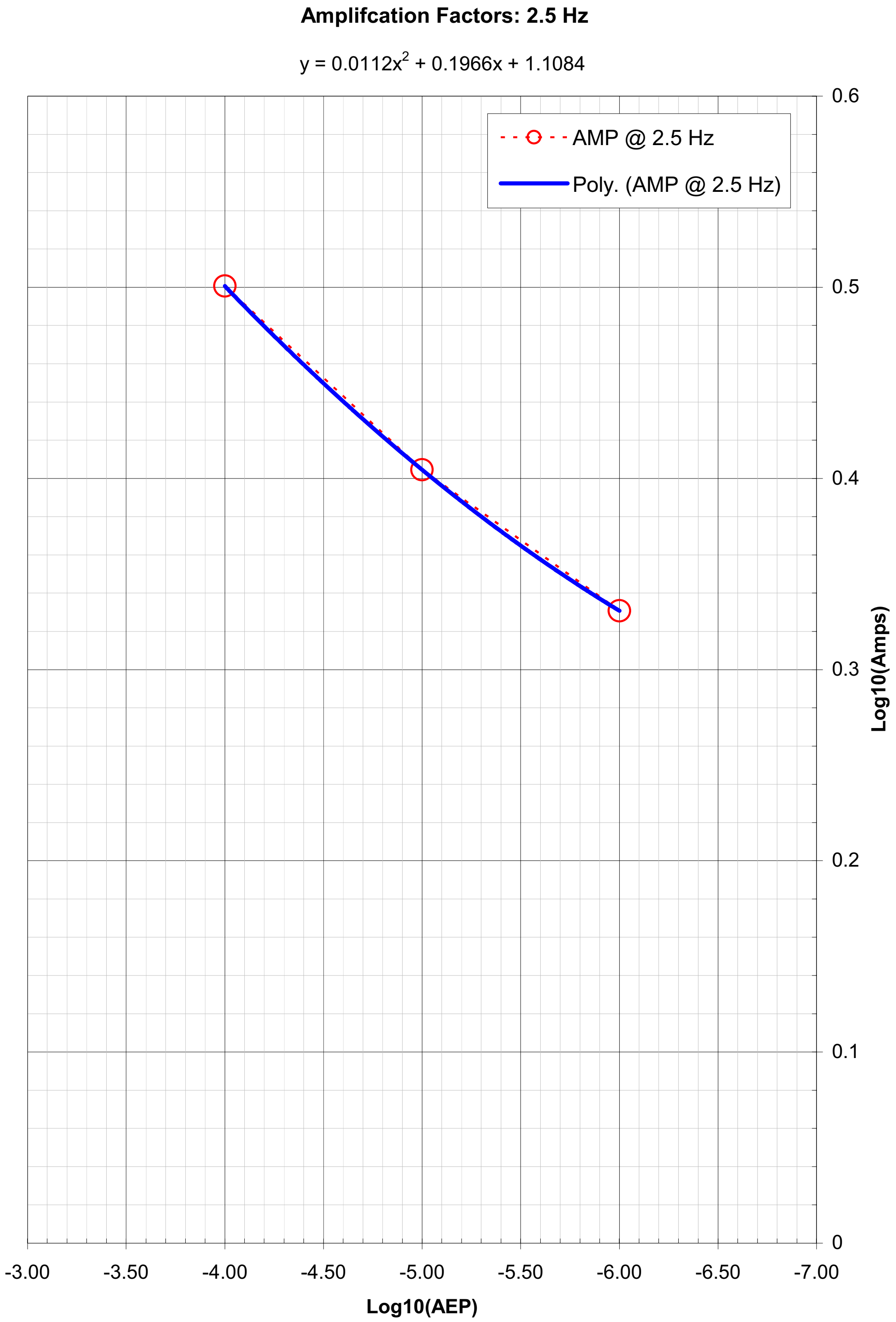


Figure 1e. Quadratic fit to the amplification values for 2.5 Hz.

Figure 1f. Quadratic fit to the amplification values for 1 Hz.

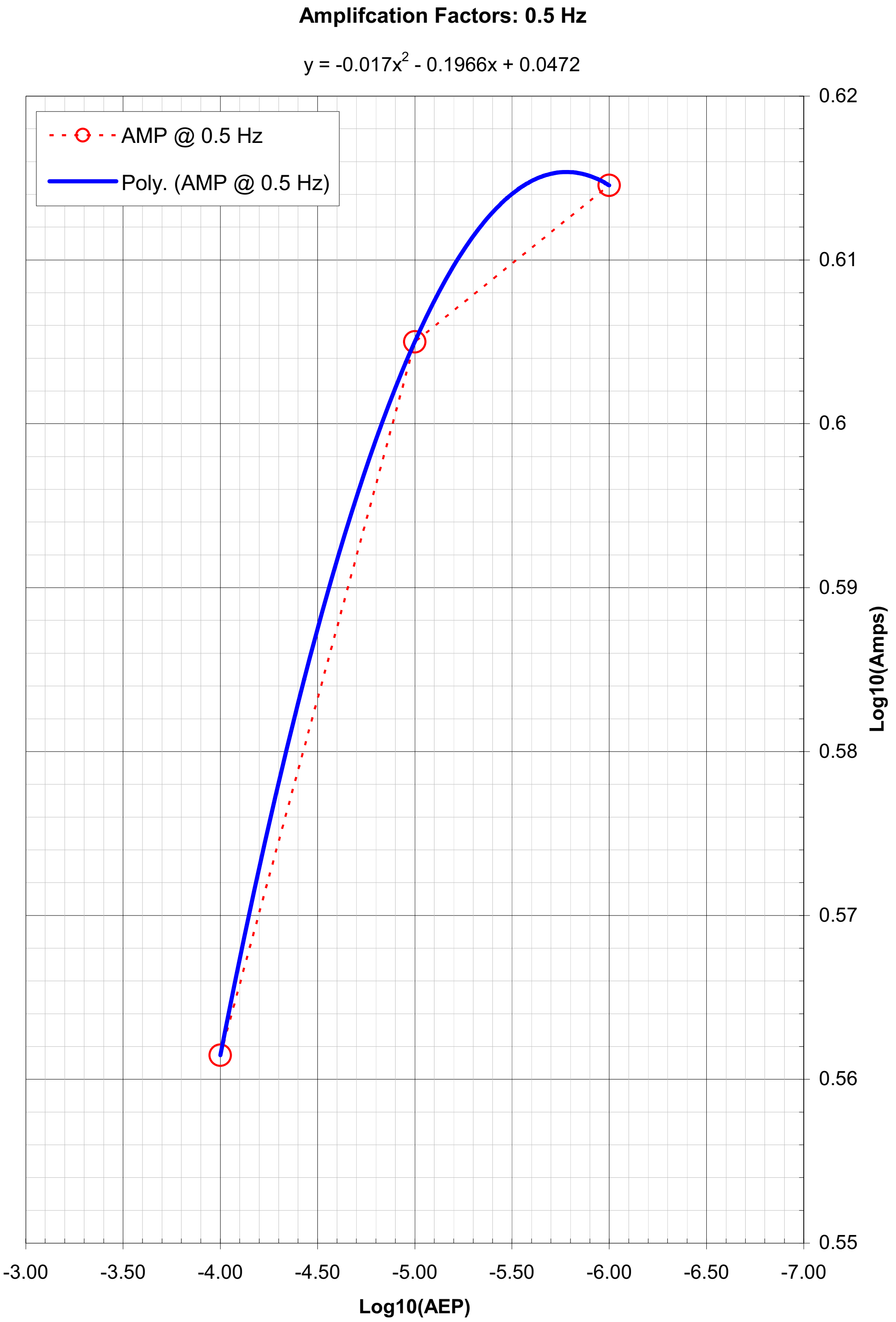


Figure 1g. Quadratic fit to the amplification values for 0.5 Hz.

Supplemental Response to RAI 2.5.2-3 (continued):

Next the hard rock hazard curves were scaled based on the functional amplification factor model for each frequency. The three hard rock ground motion values (see Table 1) corresponding to annual probability levels of 10^{-4}, 10^{-5}, and 10^{-6} were added to the suite of 25 points that defined the hard rock hazard curves (Risk Engineering Inc., 0521-ACR-032, 2006) prior to developing the top of Blue Bluff Marl hazard curves. For each of the seven frequencies, the top of Blue Bluff Marl seismic hazard curve was computed by scaling the hard rock ground motion values by the functional amplification model at each of the 28 annual probability level points that define the hard rock seismic hazard curves (see Table 2). A constraint was placed on the resulting top of Blue Bluff Marl hazard curves such that the resulting hazard curve does not decrease in ground motion for decreasing annual probability of exceedence levels. In cases where this constraint is applicable, the resulting top of Blue Bluff Marl hazard curve is vertical (i.e., the ground motion value is constant for decreasing annual probability levels).

The hard rock seismic hazard curves, amplification factors, and corresponding top of Blue Bluff Marl seismic hazard curves are listed in Table 2 for the seven frequencies. The three additional data points corresponding to probability levels of 10^{-4}, 10^{-5}, and 10^{-6} are indicated in bold. The hard rock (solid red line) and resulting top of Blue Bluff Marl seismic hazard curves are plotted in Figure 2. As indicated on each figure, the dashed blue line is based on the extrapolation of the amplification function beyond the range 10^{-4} to 10^{-6} and the green solid line with green circles is based on the interpolation of the amplification function over the range 10^{-4} to 10^{-6}.

Table 2a. Hard rock and top of Blue Bluff Marl seismic hazard curves for 100 Hz.

Hard Rock PGA (g)	Mean AEP @ PGA	AMPS @ PGA	Soil PGA (g)	Mean AEP @ PGA
1.000E-03	1.758E-02	1.4415	1.441E-03	1.758E-02
1.500E-03	1.486E-02	1.4427	2.164E-03	1.486E-02
2.000E-03	1.295E-02	1.4431	2.886E-03	1.295E-02
3.000E-03	1.039E-02	1.4429	4.329E-03	1.039E-02
5.000E-03	7.545E-03	1.4406	7.203E-03	7.545E-03
7.000E-03	5.983E-03	1.4373	1.006E-02	5.983E-03
1.000E-02	4.624E-03	1.4322	1.432E-02	4.624E-03
1.500E-02	3.430E-03	1.4244	2.137E-02	3.430E-03
2.000E-02	2.767E-03	1.4175	2.835E-02	2.767E-03
3.000E-02	2.012E-03	1.4053	4.216E-02	2.012E-03
5.000E-02	1.237E-03	1.3825	6.912E-02	1.237E-03
7.000E-02	8.156E-04	1.3589	9.512E-02	8.156E-04
1.000E-01	4.700E-04	1.3225	1.323E-01	4.700E-04
1.500E-01	2.184E-04	1.2629	1.894E-01	2.184E-04
2.000E-01	1.174E-04	1.2079	2.416E-01	1.174E-04
0.214	**0.0001**	1.1929	2.553E-01	1.000E-04
3.000E-01	4.547E-05	1.1147	3.344E-01	4.547E-05
5.000E-01	1.310E-05	0.9807	4.904E-01	1.310E-05
0.559	**0.00001**	0.9506	5.314E-01	1.000E-05
7.000E-01	5.827E-06	0.8899	6.229E-01	5.827E-06
1.000E+00	2.518E-06	0.7955	7.955E-01	2.518E-06
1.48	**0.000001**	0.6937	1.027E+00	1.000E-06
1.500E+00	9.738E-07	0.6909	1.036E+00	9.738E-07
2.000E+00	4.866E-07	0.6174	1.235E+00	4.866E-07
3.000E+00	1.723E-07	0.5140	1.542E+00	1.723E-07
5.000E+00	4.047E-08	0.3864	1.932E+00	4.047E-08
7.000E+00	1.406E-08	0.3069	2.148E+00	1.406E-08
1.000E+01	4.162E-09	0.2300	2.300E+00	4.162E-09

Table 2b. Hard rock and top of Blue Bluff Marl seismic hazard curves for 25 Hz.

Hard Rock SA(g) @25.0 Hz	Mean AEP @ 25.0 Hz	AMPS @ 25.0 Hz	Soil SA(g) @ 25.0 Hz	Mean AEP @ 25.0 Hz
1.000E-03	2.083E-02	0.9790	9.790E-04	2.083E-02
1.500E-03	1.854E-02	0.9991	1.499E-03	1.854E-02
2.000E-03	1.682E-02	1.0156	2.031E-03	1.682E-02
3.000E-03	1.437E-02	1.0418	3.126E-03	1.437E-02
5.000E-03	1.140E-02	1.0790	5.395E-03	1.140E-02
7.000E-03	9.615E-03	1.1052	7.736E-03	9.615E-03
1.000E-02	7.902E-03	1.1339	1.134E-02	7.902E-03
1.500E-02	6.210E-03	1.1669	1.750E-02	6.210E-03
2.000E-02	5.176E-03	1.1900	2.380E-02	5.176E-03
3.000E-02	3.948E-03	1.2212	3.664E-02	3.948E-03
5.000E-02	2.727E-03	1.2571	6.286E-02	2.727E-03
7.000E-02	2.074E-03	1.2783	8.948E-02	2.074E-03
1.000E-01	1.482E-03	1.2976	1.298E-01	1.482E-03
1.500E-01	9.301E-04	1.3116	1.967E-01	9.301E-04
2.000E-01	6.251E-04	1.3115	2.623E-01	6.251E-04
3.000E-01	3.235E-04	1.2870	3.861E-01	3.235E-04
5.000E-01	1.227E-04	1.1999	5.999E-01	1.227E-04
0.551	**0.0001**	1.1746	6.472E-01	1.000E-04
7.000E-01	6.043E-05	1.1041	7.729E-01	6.043E-05
1.000E+00	2.718E-05	0.9732	9.732E-01	2.718E-05
1.500E+00	1.058E-05	0.8022	1.203E+00	1.058E-05
1.54	**0.00001**	0.7918	1.219E+00	1.000E-05
2.000E+00	5.384E-06	0.6783	1.357E+00	5.384E-06
3.000E+00	2.079E-06	0.5137	1.541E+00	2.079E-06
4.09	**0.000001**	0.4013	1.641E+00	1.000E-06
5.000E+00	6.228E-07	0.3369	1.684E+00	6.228E-07
7.000E+00	2.751E-07	0.2421	1.695E+00	2.751E-07
1.000E+01	1.109E-07	0.1607	1.695E+00	1.109E-07

Table 2c. Hard rock and top of Blue Bluff Marl seismic hazard curves for 10 Hz.

Hard Rock SA(g) @10.0 Hz	**Mean AEP @ 10.0 Hz**	**AMPS @ 10.0 Hz**	**Soil SA(g) @ 10.0 Hz**	**Mean AEP @ 10.0 Hz**
1.000E-03	2.216E-02	0.9808	9.808E-04	2.216E-02
1.500E-03	1.971E-02	1.0085	1.513E-03	1.971E-02
2.000E-03	1.781E-02	1.0325	2.065E-03	1.781E-02
3.000E-03	1.501E-02	1.0732	3.219E-03	1.501E-02
5.000E-03	1.152E-02	1.1362	5.681E-03	1.152E-02
7.000E-03	9.402E-03	1.1844	8.291E-03	9.402E-03
1.000E-02	7.417E-03	1.2402	1.240E-02	7.417E-03
1.500E-02	5.547E-03	1.3075	1.961E-02	5.547E-03
2.000E-02	4.477E-03	1.3559	2.712E-02	4.477E-03
3.000E-02	3.300E-03	1.4228	4.268E-02	3.300E-03
5.000E-02	2.231E-03	1.5037	7.518E-02	2.231E-03
7.000E-02	1.678E-03	1.5583	1.091E-01	1.678E-03
1.000E-01	1.171E-03	1.6214	1.621E-01	1.171E-03
1.500E-01	6.935E-04	1.6991	2.549E-01	6.935E-04
2.000E-01	4.352E-04	1.7522	3.504E-01	4.352E-04
3.000E-01	1.960E-04	1.8038	5.411E-01	1.960E-04
0.399	**0.0001**	1.8059	7.206E-01	1.000E-04
5.000E-01	5.879E-05	1.7806	8.903E-01	5.879E-05
7.000E-01	2.462E-05	1.6906	1.183E+00	2.462E-05
0.983	**0.00001**	1.5431	1.517E+00	1.000E-05
1.000E+00	9.548E-06	1.5343	1.534E+00	9.548E-06
1.500E+00	3.251E-06	1.3053	1.958E+00	3.251E-06
2.000E+00	1.515E-06	1.1261	2.252E+00	1.515E-06
2.33	**0.000001**	1.0273	2.394E+00	1.000E-06
3.000E+00	5.063E-07	0.8684	2.605E+00	5.063E-07
5.000E+00	1.162E-07	0.5604	2.802E+00	1.162E-07
7.000E+00	4.054E-08	0.3848	2.802E+00	4.054E-08
1.000E+01	1.217E-08	0.2349	2.802E+00	1.217E-08

Table 2d. Hard rock and top of Blue Bluff Marl seismic hazard curves for 5 Hz.

Hard Rock SA(g) @5.0 Hz	Mean AEP @ 5.0 Hz	AMPS @ 5.0 Hz	Soil SA(g) @ 5.0 Hz	Mean AEP @ 5.0 Hz
1.000E-03	2.136E-02	2.6496	2.650E-03	2.136E-02
1.500E-03	1.857E-02	2.6210	3.931E-03	1.857E-02
2.000E-03	1.645E-02	2.5967	5.193E-03	1.645E-02
3.000E-03	1.341E-02	2.5569	7.671E-03	1.341E-02
5.000E-03	9.790E-03	2.4982	1.249E-02	9.790E-03
7.000E-03	7.717E-03	2.4559	1.719E-02	7.717E-03
1.000E-02	5.882E-03	2.4097	2.410E-02	5.882E-03
1.500E-02	4.282E-03	2.3583	3.537E-02	4.282E-03
2.000E-02	3.431E-03	2.3241	4.648E-02	3.431E-03
3.000E-02	2.542E-03	2.2798	6.839E-02	2.542E-03
5.000E-02	1.731E-03	2.2264	1.113E-01	1.731E-03
7.000E-02	1.287E-03	2.1877	1.531E-01	1.287E-03
1.000E-01	8.666E-04	2.1391	2.139E-01	8.666E-04
1.500E-01	4.795E-04	2.0727	3.109E-01	4.795E-04
2.000E-01	2.832E-04	2.0196	4.039E-01	2.832E-04
3.000E-01	1.157E-04	1.9412	5.824E-01	1.157E-04
0.317	**0.0001**	1.9297	6.117E-01	1.000E-04
5.000E-01	3.009E-05	1.8487	9.244E-01	3.009E-05
7.000E-01	1.127E-05	1.7987	1.259E+00	1.127E-05
0.728	**0.00001**	1.7935	1.306E+00	1.000E-05
1.000E+00	3.804E-06	1.7589	1.759E+00	3.804E-06
1.500E+00	1.085E-06	1.7321	2.598E+00	1.085E-06
1.54	**0.000001**	1.7310	2.666E+00	1.000E-06
2.000E+00	4.433E-07	1.7250	3.450E+00	4.433E-07
3.000E+00	1.227E-07	1.7320	5.196E+00	1.227E-07
5.000E+00	2.225E-08	1.7734	8.867E+00	2.225E-08
7.000E+00	6.650E-09	1.8260	1.278E+01	6.650E-09
1.000E+01	1.697E-09	1.9111	1.911E+01	1.697E-09

Table 2e. Hard rock and top of Blue Bluff Marl seismic hazard curves for 2.5 Hz.

Hard Rock SA(g) @2.5 Hz	**Mean AEP @ 2.5 Hz**	**AMPS @ 2.5 Hz**	**Soil SA(g) @ 2.5 Hz**	**Mean AEP @ 2.5 Hz**
1.000E-03	1.725E-02	6.2600	6.260E-03	1.725E-02
1.500E-03	1.405E-02	6.0626	9.094E-03	1.405E-02
2.000E-03	1.184E-02	5.9047	1.181E-02	1.184E-02
3.000E-03	8.995E-03	5.6629	1.699E-02	8.995E-03
5.000E-03	6.095E-03	5.3441	2.672E-02	6.095E-03
7.000E-03	4.668E-03	5.1404	3.598E-02	4.668E-03
1.000E-02	3.551E-03	4.9432	4.943E-02	3.551E-03
1.500E-02	2.673E-03	4.7500	7.125E-02	2.673E-03
2.000E-02	2.222E-03	4.6304	9.261E-02	2.222E-03
3.000E-02	1.715E-03	4.4702	1.341E-01	1.715E-03
5.000E-02	1.152E-03	4.2403	2.120E-01	1.152E-03
7.000E-02	8.075E-04	4.0502	2.835E-01	8.075E-04
1.000E-01	4.949E-04	3.8099	3.810E-01	4.949E-04
1.500E-01	2.417E-04	3.4983	5.247E-01	2.417E-04
2.000E-01	1.308E-04	3.2646	6.529E-01	1.308E-04
0.223	**0.0001**	3.1710	7.071E-01	1.000E-04
3.000E-01	4.770E-05	2.9374	8.812E-01	4.770E-05
5.000E-01	1.082E-05	2.5604	1.280E+00	1.082E-05
0.512	**0.00001**	2.5433	1.302E+00	1.000E-05
7.000E-01	3.643E-06	2.3467	1.643E+00	3.643E-06
1.000E+00	1.066E-06	2.1564	2.156E+00	1.066E-06
1.02	**0.000001**	2.1478	2.191E+00	1.000E-06
1.500E+00	2.466E-07	1.9876	2.981E+00	2.466E-07
2.000E+00	8.504E-08	1.8978	3.796E+00	8.504E-08
3.000E+00	1.860E-08	1.8109	5.433E+00	1.860E-08
5.000E+00	2.641E-09	1.7623	8.812E+00	2.641E-09
7.000E+00	7.020E-10	1.7670	1.237E+01	7.020E-10
1.000E+01	1.637E-10	1.8074	1.807E+01	1.637E-10

Table 2f. Hard rock and top of Blue Bluff Marl seismic hazard curves for 1 Hz.

Hard Rock SA(g) @1.0 Hz	Mean AEP @ 1.0 Hz	AMPS @ 1.0 Hz	Soil SA(g) @ 1.0 Hz	Mean AEP @ 1.0 Hz
5.000E-04	1.288E-02	1.9291	9.645E-04	1.288E-02
7.000E-04	1.042E-02	1.9348	1.354E-03	1.042E-02
1.000E-03	8.110E-03	1.9424	1.942E-03	8.110E-03
1.500E-03	5.981E-03	1.9528	2.929E-03	5.981E-03
2.000E-03	4.803E-03	1.9611	3.922E-03	4.803E-03
3.000E-03	3.572E-03	1.9735	5.921E-03	3.572E-03
5.000E-03	2.577E-03	1.9887	9.944E-03	2.577E-03
7.000E-03	2.141E-03	1.9981	1.399E-02	2.141E-03
1.000E-02	1.775E-03	2.0081	2.008E-02	1.775E-03
1.500E-02	1.399E-03	2.0216	3.032E-02	1.399E-03
2.000E-02	1.135E-03	2.0342	4.068E-02	1.135E-03
3.000E-02	7.713E-04	2.0594	6.178E-02	7.713E-04
5.000E-02	3.898E-04	2.1102	1.055E-01	3.898E-04
7.000E-02	2.167E-04	2.1606	1.512E-01	2.167E-04
1.000E-01	1.026E-04	2.2344	2.234E-01	1.026E-04
0.101	**0.0001**	2.2372	2.260E-01	1.000E-04
1.500E-01	3.752E-05	2.3525	3.529E-01	3.752E-05
2.000E-01	1.667E-05	2.4652	4.930E-01	1.667E-05
0.235	**0.00001**	2.5451	5.981E-01	1.000E-05
3.000E-01	4.667E-06	2.6782	8.035E-01	4.667E-06
0.465	**0.000001**	3.0068	1.398E+00	1.000E-06
5.000E-01	7.767E-07	3.0693	1.535E+00	7.767E-07
7.000E-01	2.178E-07	3.4280	2.400E+00	2.178E-07
1.000E+00	5.407E-08	3.9209	3.921E+00	5.407E-08
1.500E+00	1.099E-08	4.6501	6.975E+00	1.099E-08
2.000E+00	3.602E-09	5.2966	1.059E+01	3.602E-09
3.000E+00	7.659E-10	6.4394	1.932E+01	7.659E-10
5.000E+00	1.076E-10	8.4539	4.227E+01	1.076E-10

Table 2g. Hard rock and top of Blue Bluff Marl seismic hazard curves for 0.5 Hz.

Hard Rock SA(g) @0.5 Hz	**Mean AEP @0.5 Hz**	**AMPS @ 0.5 Hz**	**Soil SA(g) @ 0.5 Hz**	**Mean AEP @0.5 Hz**
5.000E-04	6.644E-03	2.4814	1.241E-03	6.644E-03
7.000E-04	5.226E-03	2.5544	1.788E-03	5.226E-03
1.000E-03	4.074E-03	2.6301	2.630E-03	4.074E-03
1.500E-03	3.131E-03	2.7098	4.065E-03	3.131E-03
2.000E-03	2.644E-03	2.7607	5.521E-03	2.644E-03
3.000E-03	2.131E-03	2.8254	8.476E-03	2.131E-03
5.000E-03	1.642E-03	2.9029	1.451E-02	1.642E-03
7.000E-03	1.359E-03	2.9587	2.071E-02	1.359E-03
1.000E-02	1.073E-03	3.0275	3.028E-02	1.073E-03
1.500E-02	7.691E-04	3.1229	4.684E-02	7.691E-04
2.000E-02	5.762E-04	3.2039	6.408E-02	5.762E-04
3.000E-02	3.521E-04	3.3373	1.001E-01	3.521E-04
5.000E-02	1.620E-04	3.5331	1.767E-01	1.620E-04
0.0653	**0.0001**	3.6442	2.380E-01	1.000E-04
7.000E-02	8.812E-05	3.6718	2.570E-01	8.812E-05
1.000E-01	4.254E-05	3.8173	3.817E-01	4.254E-05
1.500E-01	1.687E-05	3.9654	5.948E-01	1.687E-05
0.185	**0.00001**	4.0290	7.454E-01	1.000E-05
2.000E-01	8.249E-06	4.0486	8.097E-01	8.249E-06
3.000E-01	2.773E-06	4.1185	1.236E+00	2.773E-06
0.423	**0.000001**	4.1191	1.742E+00	1.000E-06
5.000E-01	6.103E-07	4.0967	2.048E+00	6.103E-07
7.000E-01	2.058E-07	3.9967	2.798E+00	2.058E-07
1.000E+00	6.005E-08	3.8054	3.805E+00	6.005E-08
1.500E+00	1.348E-08	3.4793	5.219E+00	1.348E-08
2.000E+00	4.435E-09	3.1861	6.372E+00	4.435E-09
3.000E+00	8.831E-10	2.7142	8.143E+00	8.831E-10
5.000E+00	1.142E-10	2.0961	1.048E+01	1.142E-10

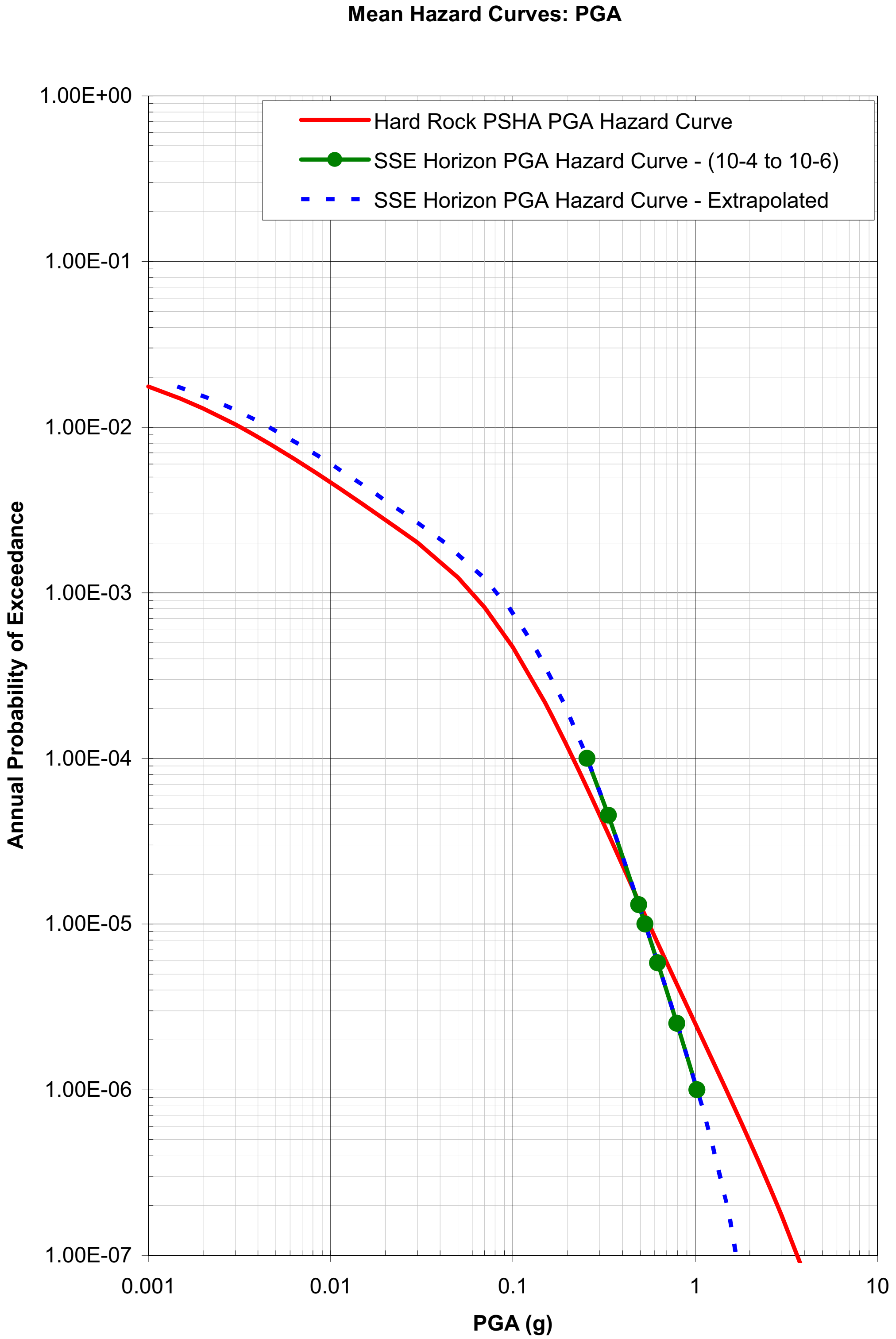


Figure 2a. Hard rock (solid red line) and top of Blue Bluff Marl (dashed blue and solid green line) seismic hazard curves for 100 Hz.

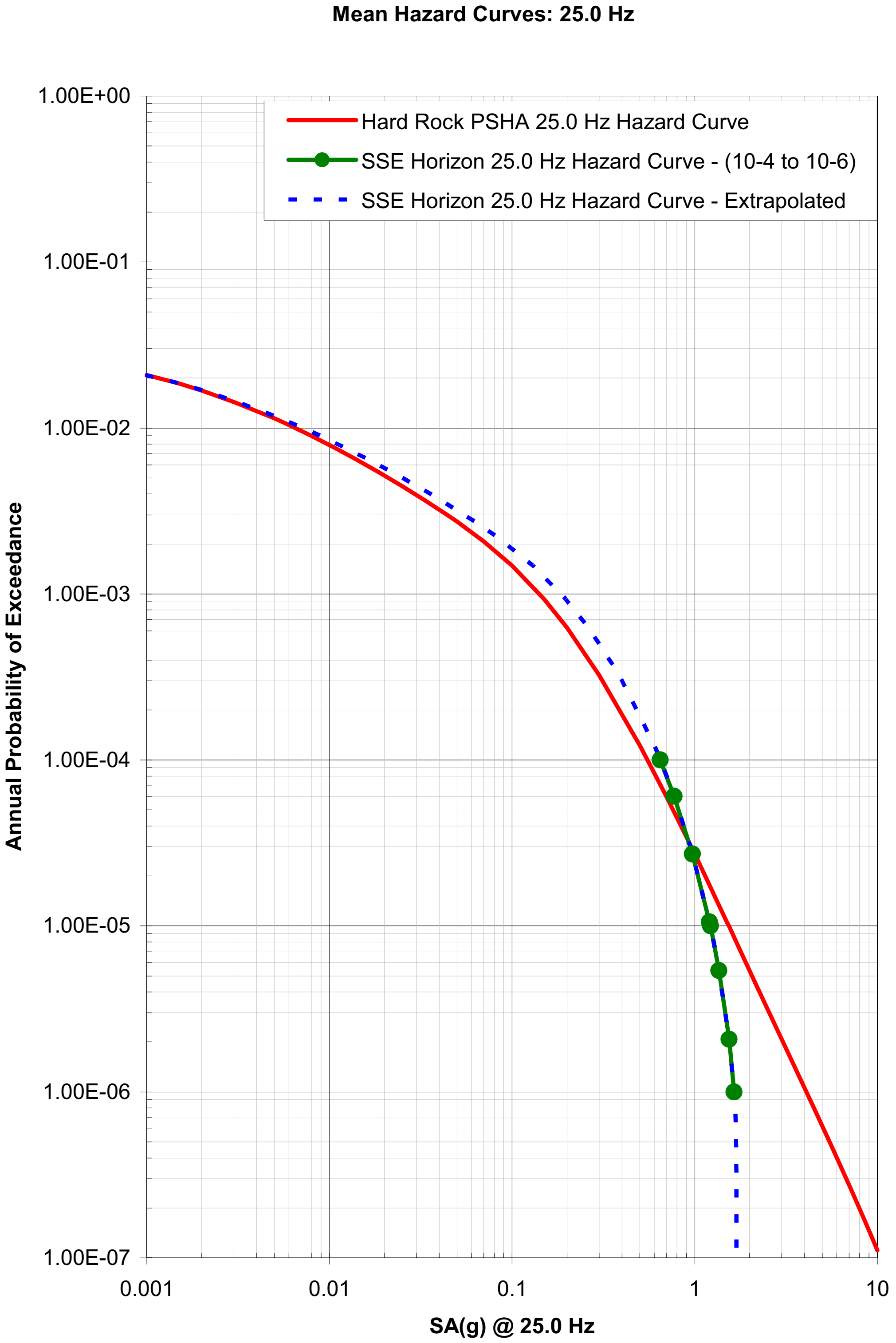


Figure 2b. Hard rock (solid red line) and top of Blue Bluff Marl (dashed blue and solid green line) seismic hazard curves for 25 Hz.

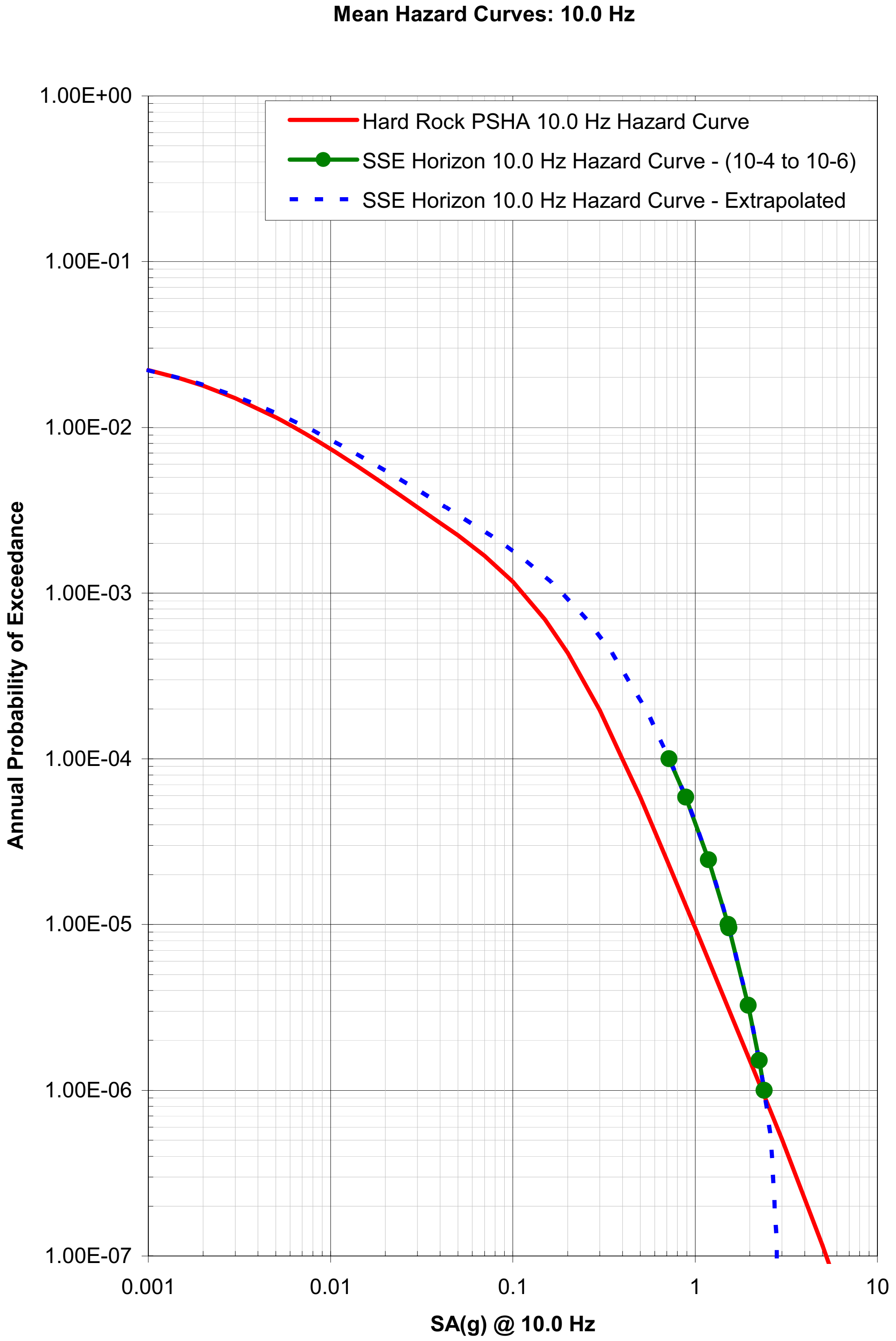


Figure 2c. Hard rock (solid red line) and top of Blue Bluff Marl (dashed blue and solid green line) seismic hazard curves for 10 Hz.

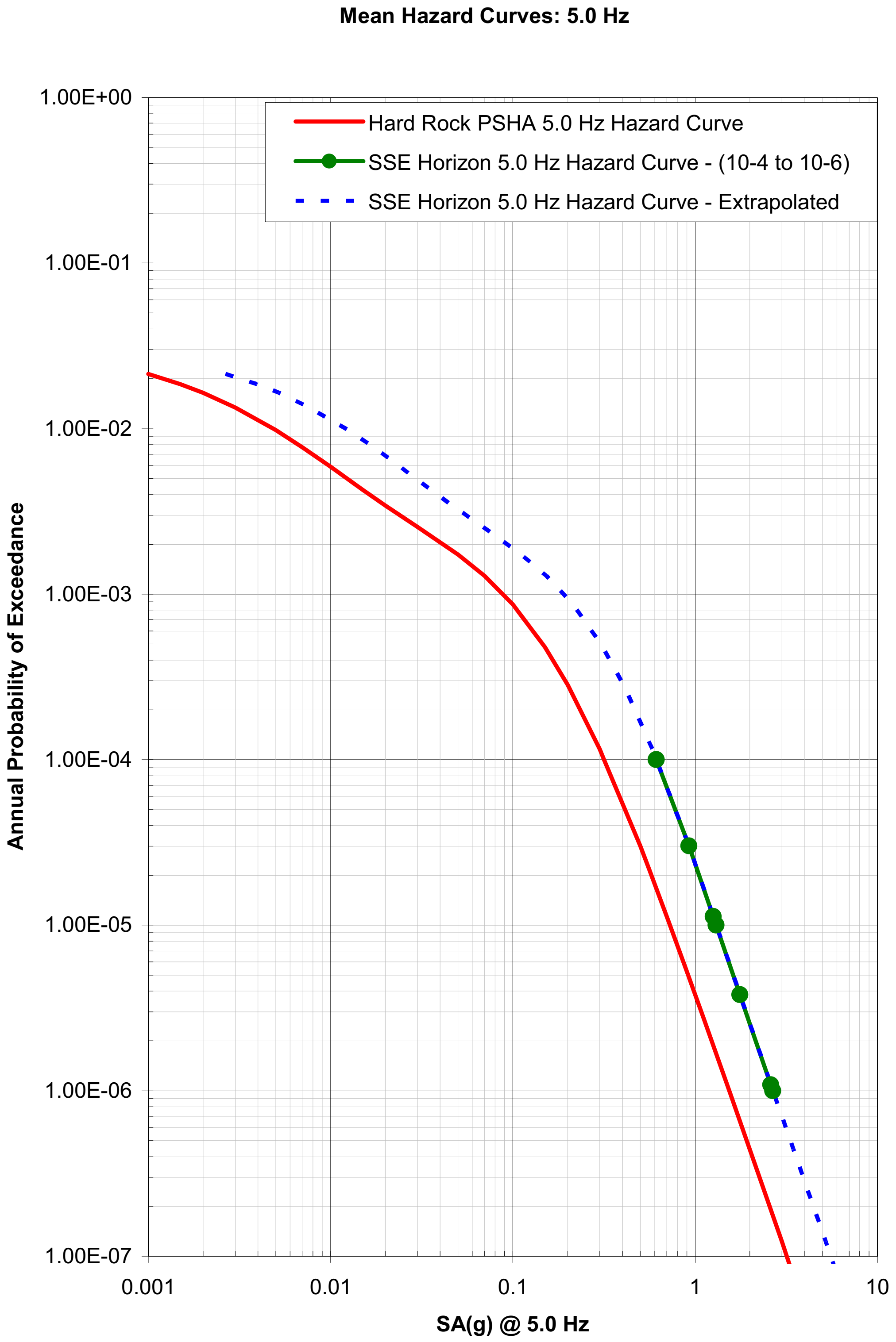


Figure 2d. Hard rock (solid red line) and top of Blue Bluff Marl (dashed blue and solid green line) seismic hazard curves for 5 Hz.

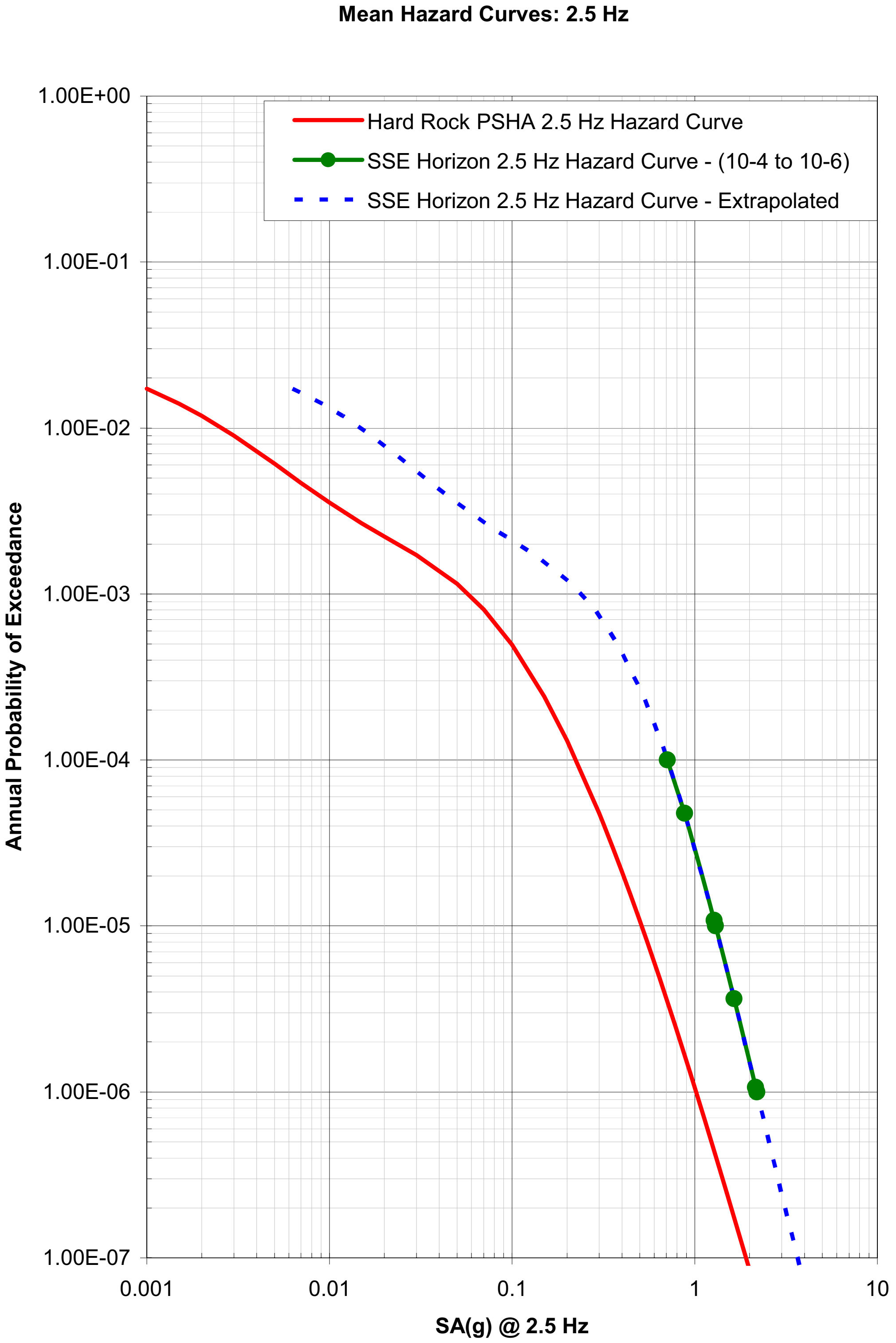


Figure 2e. Hard rock (solid red line) and top of Blue Bluff Marl (dashed blue and solid green line) seismic hazard curves for 2.5 Hz.

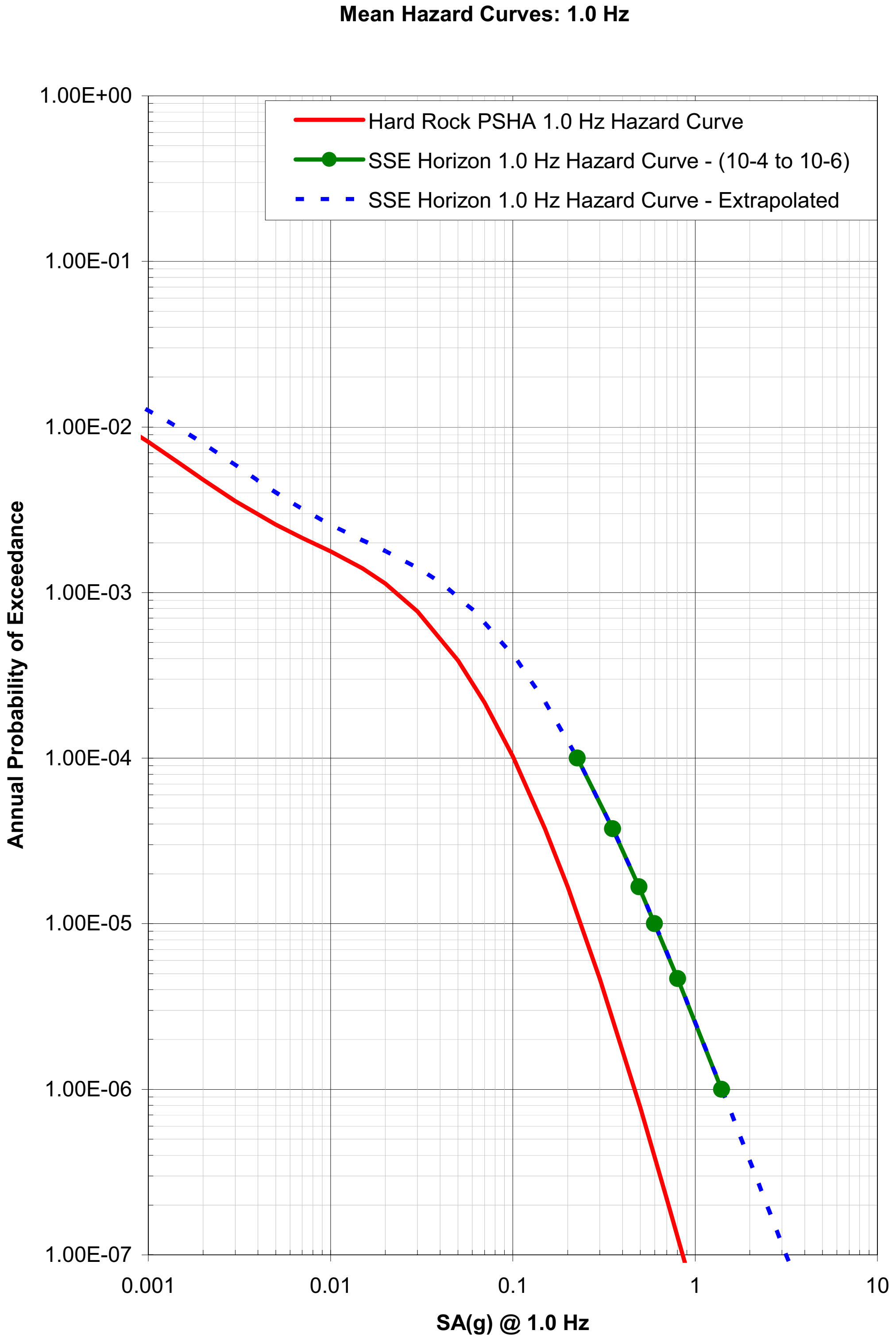


Figure 2f. Hard rock (solid red line) and top of Blue Bluff Marl (dashed blue and solid green line) seismic hazard curves for 1 Hz.

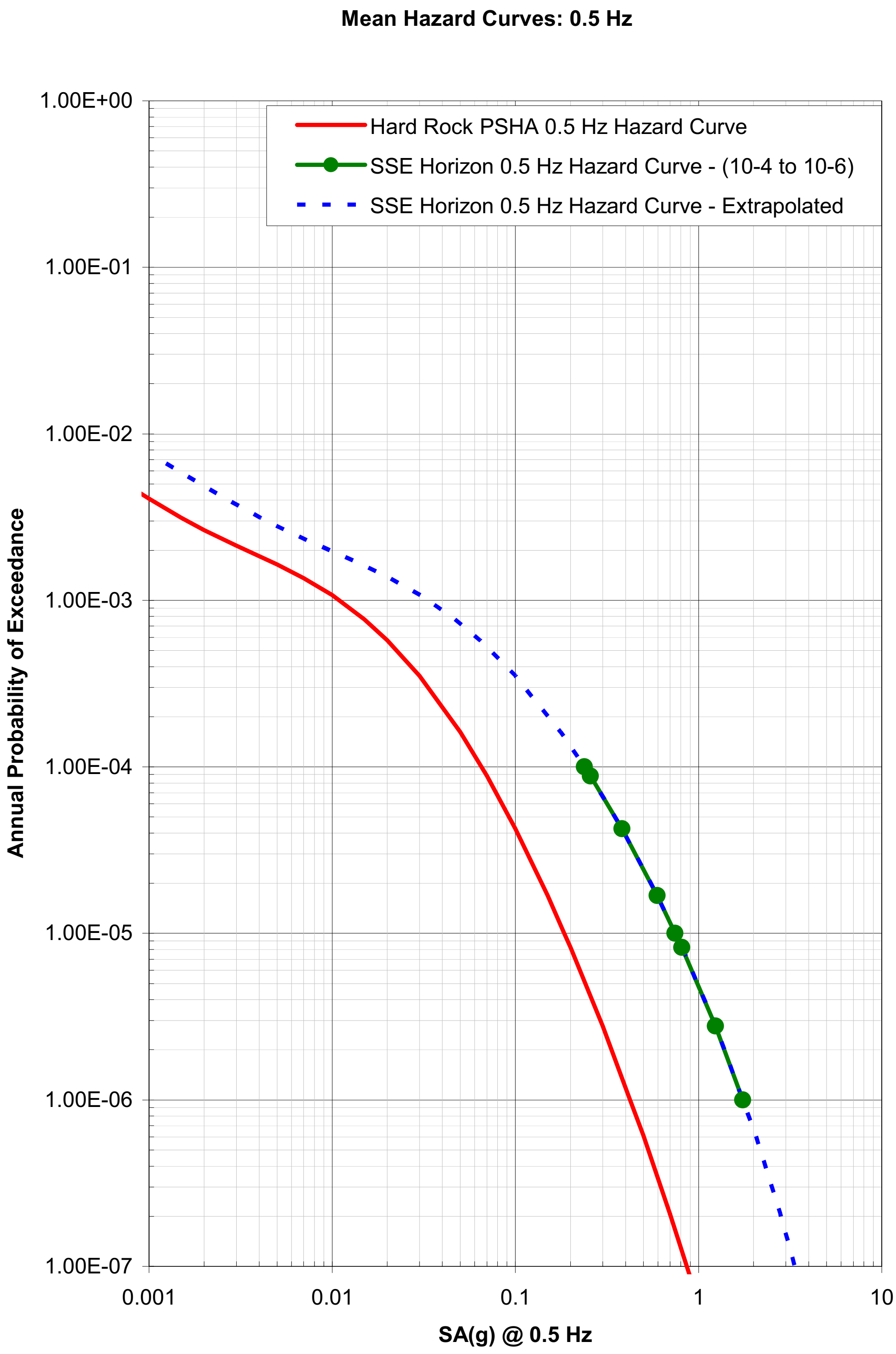


Figure 2g. Hard rock (solid red line) and top of Blue Bluff Marl (dashed blue and solid green line) seismic hazard curves for 0.5 Hz.

2.5.2-4 Supplemental information needed. [1] Please provide the questions that each of the experts involved in the SSHAC Level 2 study were asked. [2] In addition, please provide the ranges of expert opinions related to key aspects of the UCSS model (i.e. recurrence, geometry, and maximum magnitude). [3] Please also describe, with examples, the process used to combine the experts' opinions and resolve any conflicting opinions.

Response:

The SSHAC Level 2 process for updating the Charleston seismic source model involved contacting technical experts who were deemed knowledgeable about local geology and seismology, as well as characteristics of the Charleston seismic source. The experts were contacted following review of published literature. Most experts were contacted by telephone to discuss their research and their thoughts on how to model the Charleston seismic source. They were also asked of any new publications that addressed any aspect of the Charleston issue.

The experts contacted as part of this effort are listed below along with their affiliation and area of expertise:

- Dr. David Amick, SAIC, paleoliquefaction
- Dr. Martin Chapman, Virginia Polytechnic Institute, seismology/seismic source
- Dr. Chris Cramer, US Geological Survey, PSHA modeling
- Dr. Art Frankel, US Geological Survey, PSHA modeling
- Dr. Arch Johnston, Center for Earthquake Research and Information, University of Memphis, seismologist
- Dr. Richard Lee, Los Alamos National Laboratory, PSHA modeling
- Dr. Joe Litehiser, Bechtel Corp (original team leader of the 1986 Bechtel EST), PSHA modeling
- Dr. Steve Obermeier, US Geological Survey (retired), paleoliquefaction
- Dr. Pradeep Talwani, University of South Carolina, seismologist/paleoliquefaction
- Dr. Robert Weems, US Geological Survey, geologist

Before contacting the experts, a series of questions was developed to guide discussions and cover the main issues involving the Charleston earthquake process, geometry, maximum magnitude (M_{max}), and recurrence. This list of questions was the basis for communicating with researchers by telephone and is included in Attachment 1 (located directly following this RAI supplemental response). Experts were not asked to provide formal written responses. Notes were taken on the questionnaire form (and separate pages if necessary) in an effort to capture experts' thoughts and opinions during telephone interviews. In some cases, email correspondence further amplified some thoughts and opinions. Some experts felt comfortable providing opinions on most of the questions, whereas others limited their responses to their own specific area of expertise. For example, Steve Obermeier (USGS, retired) provided comments and insight on paleoliquefaction data, but did not wish to comment on specific questions regarding source geometry modeling and other parameters. Attachment 2 (located directly following this RAI supplemental response) provides a summary of the ranges of expert opinions from Amick, Chapman, Cramer, Frankel, Obermeier, Talwani, and Weems that influenced the development of the Updated Charleston Seismic Source (UCSS) model. In some interviews, selected questions were not asked if the topic was outside the expert's research area or if the interview was limited on time.The input from two experts (Lee and Litehiser) are not provided in the Attachment 2 summary since discussions with these experts was less focused on developing new source parameters for Charleston and more on general PSHA issues, history behind the development of EPRI source zones, and ideas on how to integrate the UCSS model with EPRI source models.

Because the SSHAC level 2 process does not involve bringing the experts together, there was not a forum for experts to directly question or challenge each other's assumptions or results and formally resolve any conflicting opinions. However, in the compilation of literature and expert opinions, there were instances where one expert's opinions differed from others. In these cases, the responsibility of the Technical Integrator (TI) is to "evaluate the viability and credibility of the various hypotheses with an eye toward capturing the range of interpretations, their credibilities, and uncertainties" (SSHAC 1997). Conflicting opinions were included in the model parameters in an effort to capture the range of opinion and uncertainty.

A specific example of conflicting expert opinion includes the issue of M_{max}. For the Charleston magnitude estimate, Arch Johnston favors his mean magnitude estimate of **M**7.3. His M_{max} range is larger than most other assessments for Charleston (both 1886 events and paleoliquefaction events) and does not agree with the lower estimate of 1886 earthquake by Bakun and Hopper (2004), who estimate a lower mean of **M**6.9 for the 1886 earthquake. Talwani also favors the lower magnitude estimates of near ~ **M**7 based on the geotechnical evaluations of paleoliquefaction sites that include the aging effect. The M_{max} range (**M**6.7 to 7.5) and weights that the TI committee chose for the UCSS model reflects the full range of these opinions. The M_{max} range honors the range of published literature and current professional opinion.References

(Bakun and Hopper 2004) Bakun, W.H. and Hopper, M.G., Magnitudes and Locations of the 1811-1812 New Madrid, Missouri, and the 1886 Charleston, South Carolina, Earthquakes: Bulletin of the Seismological Society of America, v. 94, no. 1, p. 64-75, 2004.

(SSHAC 1997) SSHAC, Recommendations for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and Use of Experts, Prepared by Senior Seismic Hazard Analysis Committee (SSHAC): NUREG/CR-6372, 1997.

Supplemental Response to RAI 2.5.2-4
Attachment 1: Questions for Experts

Questions for Experts – Charleston Earthquake Source
SSHAC Level 2 Update of the Charleston Source Model

Process

1. Do you believe that *Charleston earthquake process* is restricted to Charleston area or can it occur elsewhere along the East Coast (extended crust)?

Geometry

2. Is the Charleston source best characterized by (1) a large aerial source zone, (2) a small or linear aerial source zone (i.e., ECFS), or (3) both? How would you weight them?

3. Do you think the ECFS represents a tectonic feature capable of producing large earthquakes? What probability of activity would you assign to this feature?

4. Should the southern segment of the ECFS be incorporated into the Charleston source model?

5. If not, should the ECFS-s be considered an independent EQ source?

6. Does paleoliquefaction data suggest a single Charleston source or multiple sources along the coast?

Mmax

7. Do you think the Mmax values and weights in the USGS 2002 model best represent Charleston Mmax?

Recurrence

8. Is recurrence best modeled with a short RI derived from geologic data (paleoliquefaction) only or should a logic tree branch include a longer RI derived from seismicity? How would you weight these branches?

Supplemental Response to RAI 2.5.2-4
Attachment 2: Summary of Notes from Discussions with Experts

Expert: **Dr. David Amick (SAIC)**
9/16/05 telecon

Question	Response/Comment
1	He cannot say it can't happen elsewhere, but based on data in past 3-5 ka it does not appear to occur elsewhere (Charleston EQ process appears restricted to Charleston area)
2	Savannah River to Myrtle Beach may be best represented with a "large box" that produces moderate EQs. Large 1886-type EQs likely centered in Charleston area, though.
3	No opinion – hard question for him to answer
4	No opinion
5	Did not ask
6	Not clear. Bluffton and Georgetown paleoliq. Features could be caused by (1) smaller, local EQ sources or (2) large Charleston EQs occurring slightly S or N on Charleston source
7	Did not ask
8	Not sure if recurrence should include branch derived from seismicity
Other Remarks	∑ He is only comfortable answering questions pertaining to data – "only speaking to mid-late Holocene" ∑ Feels very strongly that old part of record is incomplete ∑ Most success in finding paleoliquefaction features was in ~75-125 ka deposits. Ideal area to search was in drainage ditches crossing beach ridge complexes. Did not float most rivers. ∑ He definitely thinks that Charleston could be in a cluster of activity. Does not feel that this clustering is happening elsewhere in region during mid-lat Holocene. Would be difficult to assert that 1886 is last event in present cluster.

Supplemental Response to RAI 2.5.2-4
Attachment 2: Summary of Notes from Discussions with Experts (cont'd)

Expert: **Dr. Martin Chapman (Virginia Polytechnic Institute)**
9/19/05 telcon and email; 11/08/95 telecon

Question	Response/Comment
1	Restricted to areas like Charleston where predominance of Mesozoic basins, but could occur in other basins. Reluctant to say large **M** (~7) can't occur elsewhere
2	Did not ask
3	50% weight is too high; does not believe ECFS extends into NC or VA
4	Yes
5-6	Did not ask
7	He did not drop below 7.0; he had questions on Bakun & Hopper method
8	A seismicity branch for recurrence would need to be given a low weight
Other Remarks	∑ Does not see any lineaments of seismicity within MPSSZ ∑ Does not believe Sawmill Branch Fault is actually a fault ∑ Recent magnitude 4.5 is only significant offshore EQ recorded by networks ∑ He had left off Helena Banks fault due to near total lack of seismicity offshore. The two events in 2002 off the coast of Charleston "are just outside my "area source" zone [in SCDOT model]. With 20-20 hindsight, I would modify my area zone to include them now." ∑ Depth of seismogenic crust in Charleston: 20 km is appropriate max value

Expert: **Dr. Chris Cramer (U.S. Geological Survey)**
10/7/05 telecon; 1/6/06 telecon; 9/12/05 email; 2/15/06 telecon

Question	Response/Comment
1-8	Did not ask
Other Remarks	∑ Explained some rational for past USGS characterizations of Charleston and workshop issues/suggestions ∑ Provided Cramer and Mays (2005) conference paper that evaluated effect on regional seismic hazard from changes in 1996 to 2002 USGS model ∑ Confirmed that 2002 USGS model used only mean of 550 years for recurrence and that lognormal distribution on recurrence post-dates issue of hazard maps. Prefers to represent RI in terms of a median lognormal value.

Supplemental Response to RAI 2.5.2-4
Attachment 2: Summary of Notes from Discussions with Experts (cont'd)

Expert: **Dr. Art Frankel (U.S. Geological Survey)**
9/2/05 email

Question	Response/Comment
1-8	Did not ask
Other Remarks	∑ Hesitated to comment on any new data to revise the Charleston source as he "has not been keeping up with this." Suggested speaking with Chris Cramer. ∑ Thought that workshop planned for May 2006 in Boston will have discussions on what, if any, changes to Charleston source should be included in next update of USGS national hazard maps. He thought there might be more info relevant to Mchar estimates and they would probably re-weight attenuations in next version.

Expert: **Dr. Arch Johnson (Center for Earthquake Research and Information, University of Memphis)**
11/10/05 telcon

Question	Response/Comment
1	"Difficult to answer, but given that no historic or prehistoric evidence of large EQ's along US passive margin, he would have to say that there is something special about Charleston"
2-6	Did not ask
7	He has not looked at Charleston issue since 1996. He was originally a collaborator with Bakun and Hopper (2004), but withdrew because he did not agree with model. He is more comfortable with his 1996 magnitude estimate (**M**7.3). Arch wanted to include Bhuj, India EQ, but Bakun wanted to restrict to ENA.
8	Did not ask
Other Remarks	∑ On extended crust – if he were to change anything, he would likely revise magnitude upward based on Bhuj EQ (~7.6-7.7).

Supplemental Response to RAI 2.5.2-4
Attachment 2: Summary of Notes from Discussions with Experts (cont'd)

Expert: **Dr. Steve Obermeier (U.S. Geological Survey – retired)**
9/2/05 telecon;

Question	Response/Comment
1	More liquefaction ~ 75 mi north of Georgetown (near Southport, NC) suggests strong shaking has occurred at least this far to the north.
2	"no idea, not qualified"
3	"not qualified"
4	"not qualified"
5	"not qualified"
6	Multiple sources along coast; Bluffton had very little historic liquefaction in 1886 which suggests source south of Charleston
7	"not qualified"
8	"not qualified"
Other Remarks	∑ He looked for paleoliquefaction features in Savannah, GA but found none. Not the most rigorous study. ∑ Bluffton area – He thinks many young looking liquefaction features interpreted by Talwani as evidence for 1886 liquefaction are instead related to hurricanes and uprooting of trees.

Expert: **Dr. Pradeep Talwani (University of South Carolina)**
9/8/05 telecon

Question	Response/Comment
1	Restricted to Charleston area
2	80% - Charleston zone (smaller rather that large areal zone) 20% - ECFS
3	See #2
4	Yes, but at about 20% weight
5	Did not ask
6	Multiple sources – Georgetown in the north is likely different source; Event C is not at Charleston, but does occur at Georgetown

7	Geotechnical studies to estimate M for paleoevents in Charleston. Hu et al (2002) results predicted higher magnitudes. More recent work to include aging effect has reduced magnitude in the ~6.8-7.0 range. He prefers the newer and lower magnitude estimates for Charleston.
8	Events A and B are represented by widespread, good data – these largely guided short RI interpretation. Did not respond with specific weights on braches or if seismicity-based recurrence worth considering.
Other Remarks	∑ Does not believe Adams Run fault is a fault given that he does not see any geophysical evidence ∑ Woodstock fault south – cannot confidently extend south due to large buried pluton; no geophysical evidence

Expert: **Dr. Robert Weems (U.S. Geological Survey)**
9/9/05 telecon

Question	Response/Comment
1	Atypical of rest of Coastal Plain
2	Prefers source zone
3	"uncertain"
4	Not sure about ECFS
5	Did not ask
6	Possibly, but bulk of deformation is in Charleston
7-8	Did not ask
Other Remarks	∑ Charleston may be a step over between "Coastal Plain Fall Line" and Helena Banks fault ∑ Believes clustering is likely explanation for short Charleston RI ∑ Cape Fear Arch – no warping in last 3 Ma (<10 ft) ∑ Pliocene Yorktown Fm has been tectonically deformed and offset, but can't find anything younger that is faulted.

2.5.2-8 Please supplement RAI response by providing written documentation, in the form of a letter, of personal communication provided by Mr. Stephen Obermeier, to clarify negligible probability for large inland earthquakes.

Response:

In a conference call with NRC staff on May 17, 2007, it was resolved that a letter of personal communication from Dr. Steve Obermeier (USGS, retired) is not required in response to this supplemental RAI. Instead, SNC provides a summary of conversations with Dr. Obermeier regarding the Charleston seismic source.

As part of the SSHAC Level 2 study performed for the Vogtle ESP application, William Lettis & Associates geologists interviewed Dr. Obermeier as an expert on liquefaction features in the southeastern U.S. Dr. Obermeier stated that liquefaction evidence in South and North Carolina suggests the possibility of multiple seismic sources along the coast, but declined to comment on the inland extent of possible seismic sources.

In a telephone conversation on September 2, 2005, Dr. Obermeier stated that he believes the liquefaction data suggest multiple seismic sources along the coast. Specifically, Dr. Obermeier cited liquefaction features near Southport, North Carolina (north of the northern limit of 1886 liquefaction) as evidence for a possible northern source. Likewise, Dr. Obermeier cited numerous pre-historic liquefaction features and very few 1886 liquefaction features near Bluffton, South Carolina as evidence for a possible southern source. When asked how he would characterize the geometry of the Charleston seismic source, Dr. Obermeier declined to comment, stating that he was not qualified to do so.

Obermeier et al. (1990) and Obermeier (1996) report six inland paleoliquefaction (pre- 1886) sites along the Edisto River. Amick et al. (1990a, 1990b) map four of these same sites as 1886 liquefaction sites (their sites 117, 119, 120, and 121; Obermeier's sites BRA, SPR, GR, and CV) and cite Obermeier as the data source. Obermeier and Amick are at odds with their interpretation of the timing of these liquefaction episodes at these four sites. Whether these Edisto River features are historic or pre-historic (or both) has important implications for defining the geometry of the Charleston seismic source.

In a telephone conversation on April 4, 2007, Dr. Obermeier stated that it is likely that these four Edisto River sites include both historic *and* pre-historic liquefaction features. Moreover, Dr. Obermeier repeatedly stated that the distance separating the Edisto River sites from the 1886 meizoseismal area is less than the distance separating the meizoseismal area from the northeastern-most and southwestern-most 1886 coastal liquefaction features. This is an important observation because it suggests that the inland extent of liquefaction features from pre-historic earthquakes is no greater than that for the 1886 Charleston earthquake. In other words, a seismic source located inland from that which produced the 1886 earthquake is not required to explain available liquefaction data. When asked if liquefaction evidence requires the presence of an inland seismic source, Dr. Obermeier stated that the data are consistent with a coastal source or sources.

Whereas an inland source of large earthquakes cannot be precluded by available data, the available data are consistent with a source localized in the 1886 meizoseismal area. Moreover, the preponderance of data suggests a source localized in the 1886 meizoseismal area.

References

(Amick et al. 1990a) Amick, D., Gelinas, R., Maurath, G., Cannon, R., Moore, D., Billington, E., and Kemppinen, H., Paleoliquefaction Features Along the Atlantic Seaboard: U.S. Nuclear Regulatory Commission Report, NUREG/CR-5613, p. 147, 1990a.

(Amick et al. 1990b) Amick, D., Maurath, G., and Gelinas, R., Characteristics of Seismically Induced Liquefaction Sites and Features Located In the Vicinity of the 1886 Charleston, South Carolina Earthquake: Seismological Research Letters, v. 61, no. 2, p. 117-130, 1990b.

(Obermeier 1996) Obermeier, S., Liquefaction-induced features: in *Paleoseismology*, J. McCalpin (ed.), Academic Press, San Diego, p. 331-396, 1996.

(Obermeier et al. 1990) Obermeier, S.F., Jacobson, R.B., Smoot, J.P., Weems, R.E., Gohn, G.S., Monroe, J.E., and Powars, D.S., Earthquake-induced liquefaction features in the coastal setting of South Carolina

and in the fluvial setting of the New Madrid seismic zone: U.S. Geological Survey professional paper 1504, p. 44, 1990.

2.5.2-16 Please provide the probabilities of activities for the EPRI sources that are not already provided in Tables 2.5.2-2 through 2.5.2-7.

<u>Response</u>**:**

None of the EPRI-SOG teams specifically defined a zone identified as "Eastern Tennessee Seismic Zone." Each EPRI-SOG team did define one or more sources that encompass seismicity in eastern Tennessee and, in most cases, surrounding regions. The probabilities of activity for these sources are as follows:

Team	Source number	Source Name	Prob. of activity
Bechtel	24	Bristol trends	0.25
	25	NY-AL lineament	0.30
	25A	NY-AL lineament (alternative)	0.45
Dames & Moore	04	Appalachian fold belt	0.35
	4A	Kinks in Appalachian fold belt	0.65
Law Engineering	17	Eastern basement	0.62
Rondout	13	So. NY-AL lineament	1.0
	25	So. Appalachians	0.99
	27	TN-VA border	0.99
Weston Geophysical	24	NY-AL Clingman	0.90
Woodward-Clyde	31	Blue Ridge comb.	0.024
	31A	Blue Ridge comb. (alternative)	0.211

Source: Risk Engineering, Inc (1989). *EQHAZARD Primer*, Elec. Power Res. Inst., Palo Alto, CA, Rept. NP-6452-D, June.

2.5.2-18 Please provide justification for the selection of the geometries shown in SSAR Figure 2.5.2-16 as well as RAI Figure 2.5.2-18A. Specifically, why were these particular geometries selected over other possible geometries? In addition, please justify the exclusion of the recent seismicity associated with the Helena Banks fault zone from all of the selected geometries.

Response:

Several areas were used to examine the effect of the new regional earthquake catalog. RAI figure 2.5.2-18A shows these areas. The areas were selected because sensitivity studies showed that seismic sources in the vicinity of the site, in the Charleston, South Carolina region, and in northwestern South Carolina were the main contributors to seismic hazard at the Vogtle site. The large rectangular source surrounding the site spans 2.5° longitude by 2° latitude, the source representing Charleston, South Carolina, spans 1° longitude by 1° latitude, and the source in northwestern South Carolina spans 1° longitude by 1° latitude. These sources were selected as representative of the regions important to seismic hazard analysis. In addition, the large source surrounding the site was divided with a diagonal line to capture seismicity in the northeast half of the source, so that seismicity would not be combined with the relatively aseismic, southwest half of the source.

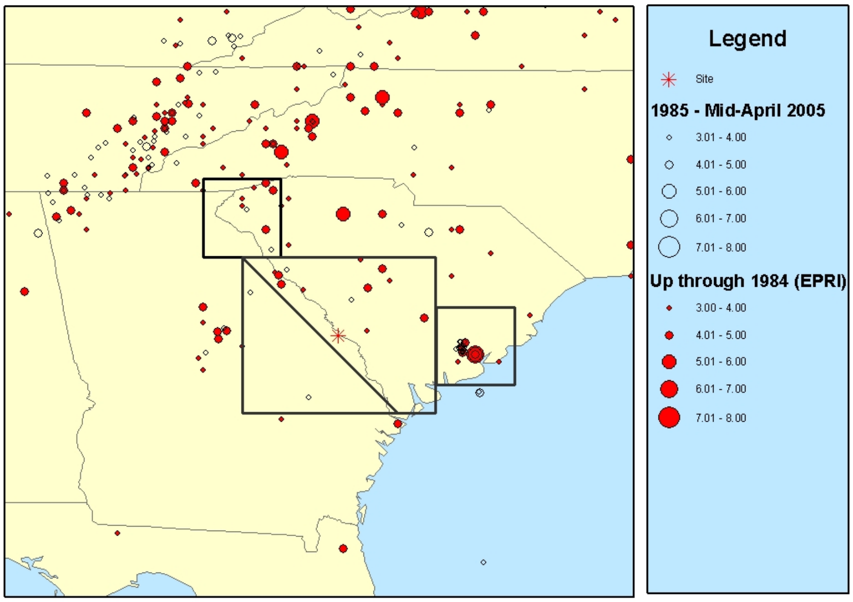


Figure 2.5.2-18A: Seismicity in southeastern US and areas used to examine seismicity effects.

All four regions showed the same result, that additional seismicity from 1985 to mid-2004 does not increase estimated activity rates in the area around the Vogtle site. As an example, RAI Figure 2.5.2-18B shows the effect of additional seismicity in the square, northwestern South Carolina source shown in RAI Figure 2.5.2-18A. The estimated activity rate decreases, similar to what is shown in SSAR Figure 2.5.2-18. We conclude that any region in South Carolina that would affect the seismic hazard of Vogtle would have estimated activity rates that stay constant or decrease, if the new regional earthquake catalog were added to the analysis.

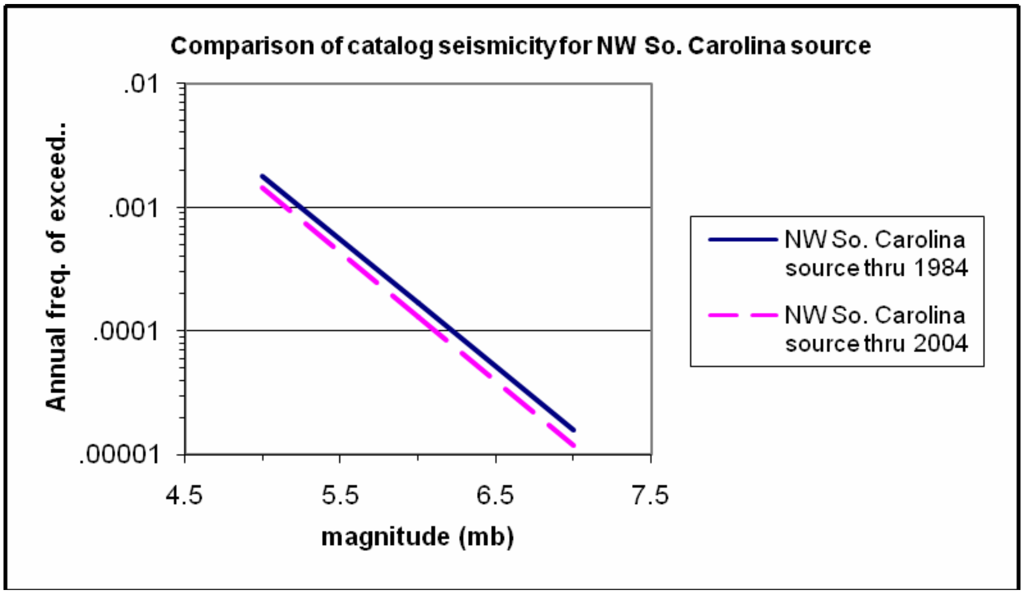


Figure 2.5.2-18B: Comparison of seismicity for northwestern South Carolina

The seismicity in the area of the Helena Banks fault zone was not considered separately because low-magnitude seismicity offshore would not contribute significantly to seismic hazard at the Vogtle site. As an example, the low-magnitude seismicity in the Charleston region is modeled in the seismic hazard calculations with an exponential magnitude distribution using the EPRI-SOG team interpretations of seismicity rates. The seismic hazard from this model is negligible compared to the seismic hazard from the large-magnitude, characteristic model of earthquakes in the Charleston region.

2.5.2-19 Supplement the RAI with additional information related to STEP 5. Please include a definition, and a figure (or table), of the envelope motion. The response to this RAI states

"The AFs represent the mean spectral acceleration (SA) at the control point, divided by input SA at hard rock, at each frequency. At each frequency, the soil envelope motion [at the control point horizon (86' depth')] is determined. This is the motion (HF or LF) that gives the higher mean soil motion, for that structural frequency. At frequencies above 8 Hz, this is always the HF motion. At frequencies below 2 Hz, this is always the LF motion."

However, it is not clear if the envelope motion refers to the envelope of the mean AFs or envelope of the mean response spectra at the control point.

Response:

(Revision for "Step 5" only)

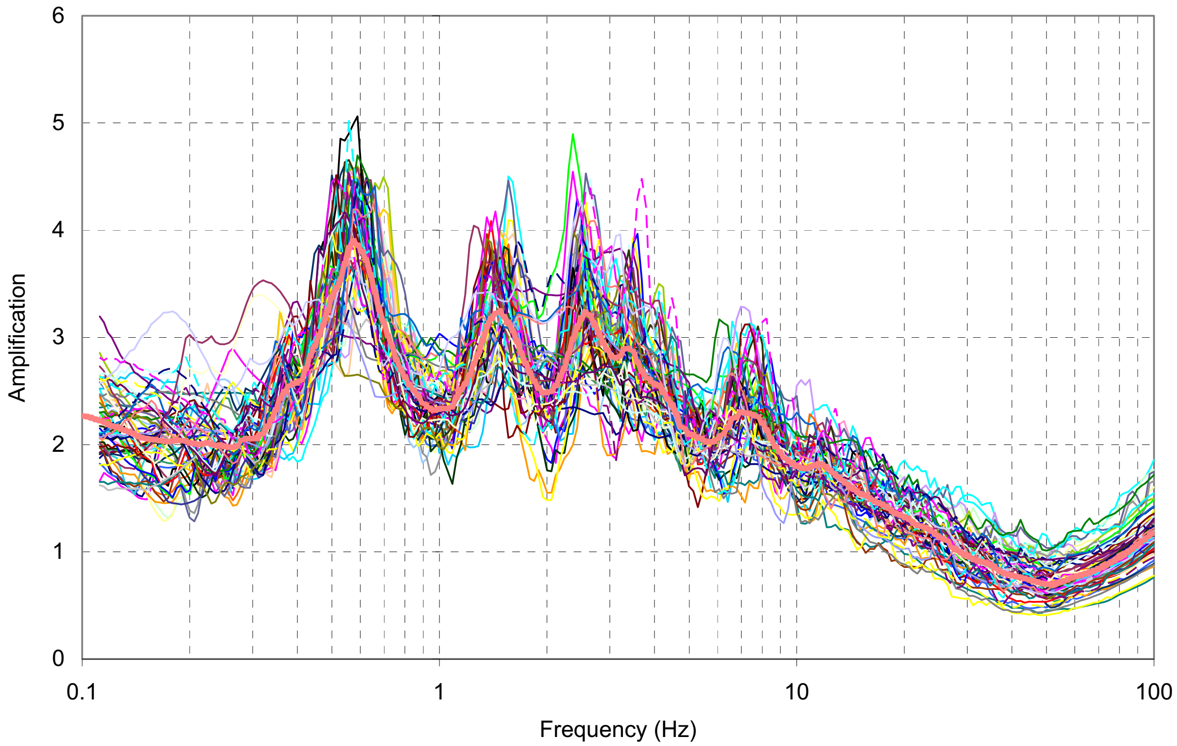
STEP 5: SOIL AMPLIFICATION FACTORS

SSAR 2.5.2.5.1, STEP 5: "The soil amplification factors (AFs) are developed at 300 frequencies using analyses described in this section based on the HF and LF hard rock spectral shapes. The AFs represent the mean spectral acceleration (SA) at the control point, divided by input SA at hard rock, at each frequency. At each frequency, the [soil] envelope motion [at the control point horizon (86' depth)] is determined. This is the motion (HF or LF) that gives the higher mean soil motion, for that structural frequency and MAFE. At frequencies above 8 Hz, this is always the HF motion. At frequencies below 2 Hz, this is always the LF motion. At intermediate frequencies, the envelope motion depends on the frequency and the MAFE."

<u>STEP 5A</u>: The mean and standard deviation of amplification factors [AFs] (soil SA divided by rock SA at each of the 300 structural frequencies) is calculated using the 60 randomized sets of soil/rock characteristics. (Means and standard deviations are calculated logarithmically.) This results in 12 sets of mean AFs (one set being for the 300 structural frequencies), as follows:

Ground motion levels [10^{-4}, 10^{-5}, and 10^{-6}]	3
Frequency bands [HF and LF target spectra]	× 2
Material curve models [EPRI and SRS]	× 2
Depth horizon [86 feet]	<u>× 1</u>
Total sets of mean AFs:	12

SSAR Figure 2.5.2-37, repeated below, illustrates the 60 individual AFs and the logarithmic mean AF across the frequency range of 0.1 Hz to 100 Hz, for the 10^{-4} MAFE, HF input, EPRI mean material curves, and 86' depth.



SSAR Figure 2.5.2-37 Typical Results of Spectral Amplification at 86-ft Depth (Top of Blue Bluff Marl) Using EPRI Degradation Curves for High Frequency Time Histories of 10^{-4} MAFE Input Motion Level

STEP 5B: The mean AFs for the EPRI and SRS material curves are equally weighted, to give 6 mean AFs across the frequency range 0.1 Hz to 100 Hz, for the control point horizon. These 6 mean AFs correspond to the 3 ground motion levels and to the HF and LF input motions.

STEP 5C: The controlling HF or LF input motion is determined over the frequency range 0.1 Hz to 100 Hz for each MAFE, by examining the envelope of soil response spectra at the control point location (86' depth) due to the HF and LF rock motion. Figure 2.5.2-Y1 gives an example of logarithmic mean amplification factor as a function of frequency for the control point location for the HF and LF 10^{-5} motion. Figure 2.5.2-Y2 gives an example of the resulting 10^{-5} site response spectra calculated by multiplying the 10^{-5} input rock motion by the logarithmic mean AF values from Figure 2.5.2-Y1. Note from Figure 2.4.2-Y1 that at very low frequencies the HF amplification factor exceeds the LF amplification factor, because the HF input rock motion does not include much low-frequency content (the denominator of the ratio of site response divided by rock input motion is low). Figure 2.5.2-Y2 shows that, at high frequencies, the HF site response spectrum equals or exceeds the LF site response spectrum and at low frequencies, the reverse is true. This means that the HF input rock motion will control the high frequencies (above 8 Hz) soil responses and the LF input rock motion will control the low frequencies soil responses (below 2 Hz). In between, the controlling motion, which is the maximum soil response, depends on the MAFE and the frequency. This step results in one set of mean AFs (across the frequency range 0.1 Hz to 100 Hz) for each MAFE.

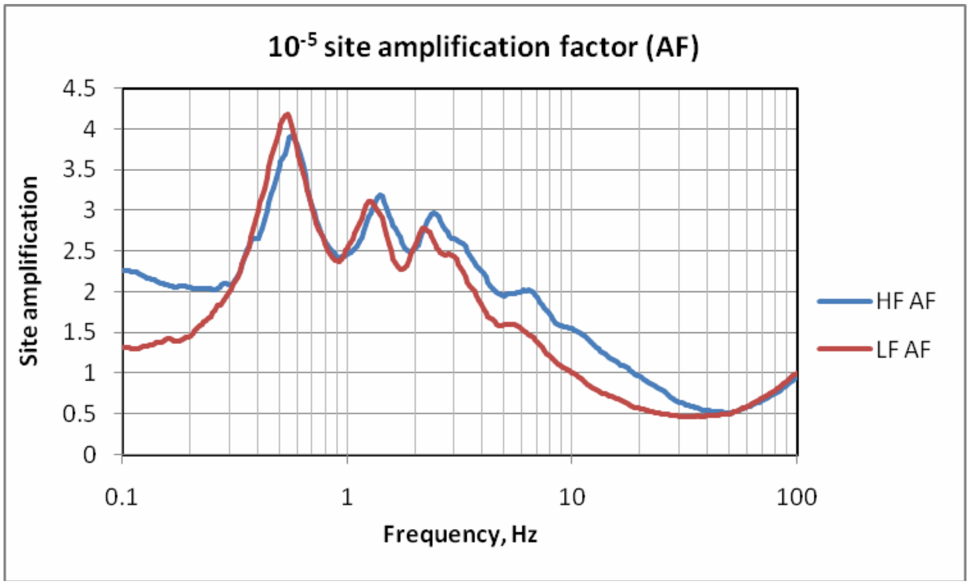


Figure 2.5.2-Y1: Example logarithmic mean spectral amplification factors for 10^{-5} rock input motion, for HF and LF earthquakes.

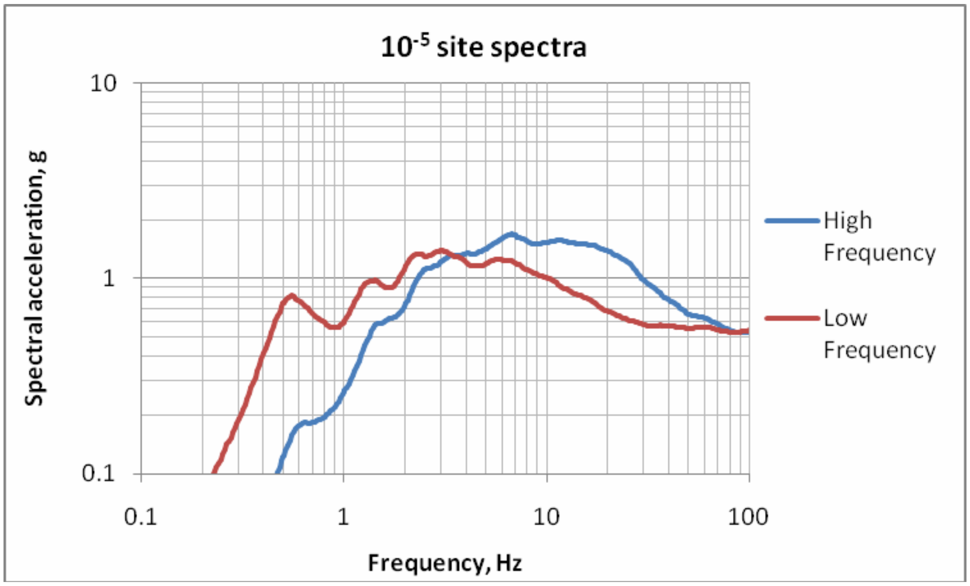


Figure 2.5.2-Y2: Example 10^{-5} site response spectra for HF and LF input motion.

2.5.2-22 The response to this RAI states that

> **"For a given suite of 30 time histories, the spectral matching criteria given in NUREG/CR-6728 were followed. Specifically, item (e) of the general criteria recommended for evaluating the adequacy of the artificially developed ground motions ..."**
>
> **Please explain whether the additional criteria listed in NUREG/CR-6728 were also satisfied. If these additional criteria were not satisfied, please provide justification for not doing so.**

Response:

For the site response analysis, 30 acceleration horizontal time histories were modified to be spectrum compatible to given target spectra. Target spectra were developed for both the high- and low-frequency cases at each of the three annual probability levels: $1x10^{-4}$, $1x10^{-5}$, and $1x10^{-6}$. This resulted in a total of 180 spectrum compatible acceleration time histories for the site response analysis. For a given suite of 30 time histories, the spectral matching criteria given in NUREG CR-6728 were used as guidance.

Following NUREG CR-6728 criterion (c), the target spectra were defined for 300 equally log-spaced frequency values between 0.1 Hz and 100 Hz (PGA). Input time histories for the spectral matching procedure were selected based on the deaggregation of the seismic hazard and all of these selected time histories are acceptable under criterion (b) in terms of duration, frequency window and maximum frequency.

As specified in the NUREG CR-6728 spectral matching criteria, when using multiple sets of time histories, the mean (linear average) of the 5% damped response spectra (in this case for a given suite of 30 matches) can be used in place of the individual 5% damped response spectra for checking against the target response spectra. Criteria (a), (d), and (e) define the matching requirements for the mean response spectra and the given target response spectra. These criteria are defined for the frequency range of 0.2 to 25 Hz. For the three low frequency cases (i.e., 10^{-4}, 10^{-5}, and 10^{-6}) the mean of the suite of spectrum compatible time histories are acceptable under criteria (a), (d), and (e). For the three high frequency cases, the spectrum compatible time histories are acceptable for the more restrictive frequency range of 0.33 Hz to 25 Hz. Graphically, the comparison between the mean spectra, the target spectrum, and the bounding scaled target spectrum are shown in Figures 1-6 for the six cases. As can be seen for the three high frequency cases, the mean spectrum for frequencies between 0.33 Hz and 0.2 Hz falls below the respective target spectrum, but this frequency range for the high frequency cases does not impact any calculations for the development of the SSE spectra (i.e., the low frequency range is controlled by the site response analysis from the low frequency cases not the high frequency cases).

Criterion (f) presents guidance on the resulting peak ground motion ratios (e.g., PGV/PGA and $PGA*PGD/PGV^2$) and Arias duration of the spectrum compatible time histories. During the spectral matching procedure for each individual time history, an emphasis was placed on maintaining the Arias duration of the initial input starting time history. In addition, the overall phasing of the input acceleration, velocity, and displacement time history was maintained during the spectral matching procedure. Thus, the Arias duration and the relative peak ground motion values were maintained to be consistent with the original input empirical strong ground motion recordings during the spectral matching analyses.

Finally, criterion (g) was not checked because it does not apply. The site response analyses were performed for a single horizontal component not pairs of horizontal components.

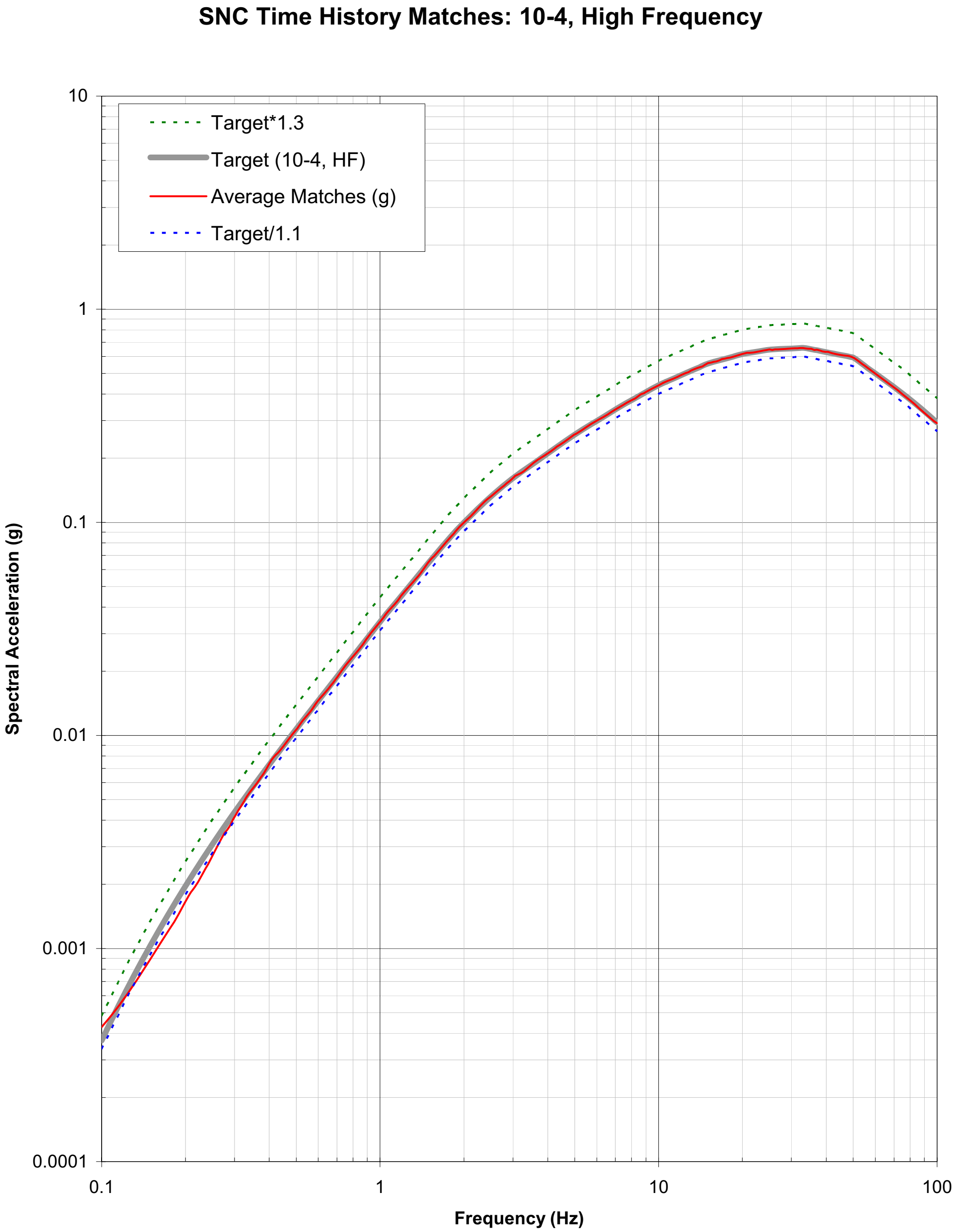


Figure 1. Comparison between the linear average of the suite of 30 spectrum compatible time histories (red line), target spectrum (thick gray line), target spectrum divided by 1.1 (dashed blue line), and target spectrum multiplied by 1.3 (dashed green line) for the high frequency 10^{-4} case.

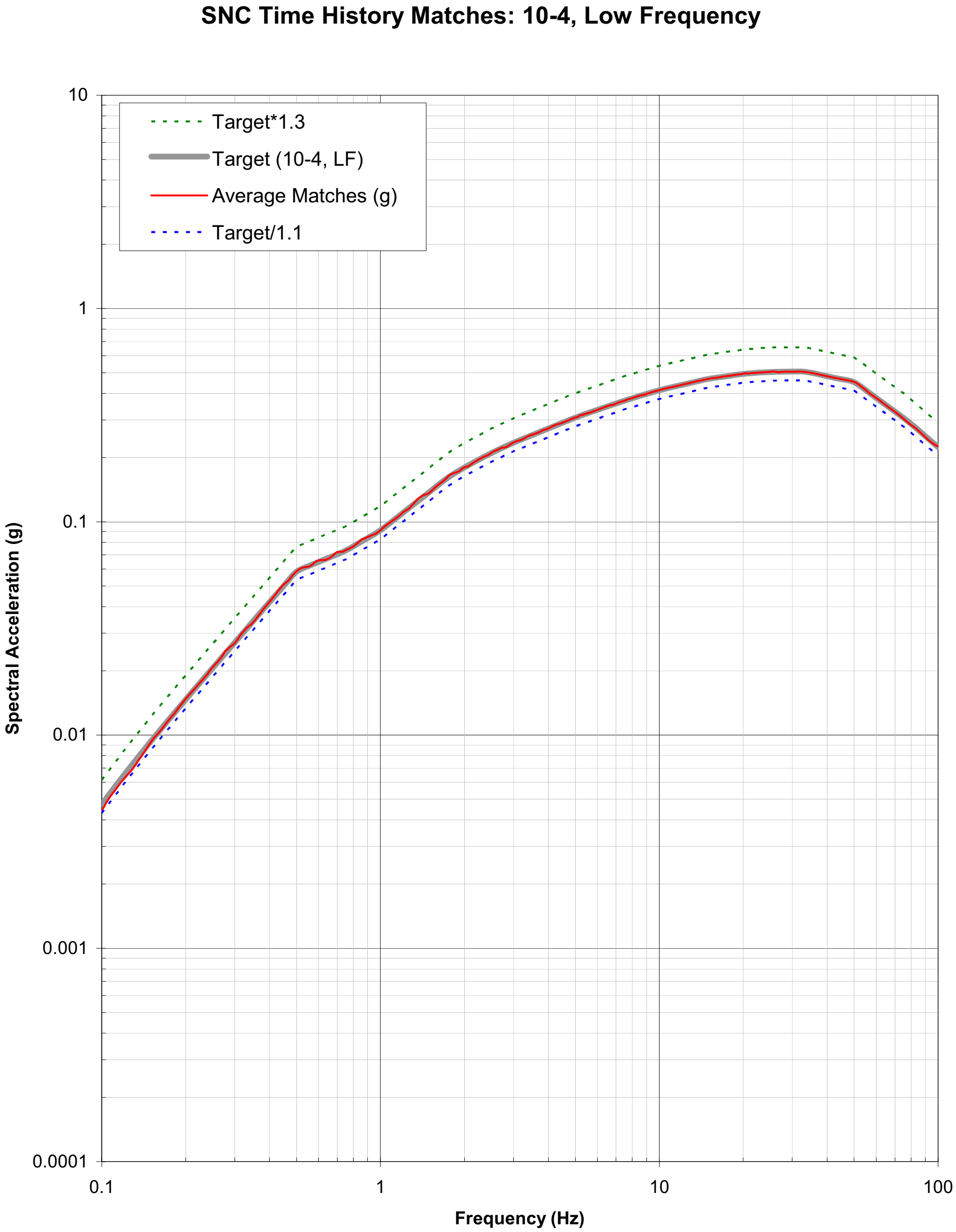


Figure 2. Comparison between the linear average of the suite of 30 spectrum compatible time histories (red line), target spectrum (thick gray line), target spectrum divided by 1.1 (dashed blue line), and target spectrum multiplied by 1.3 (dashed green line) for the low frequency 10^{-4} case.

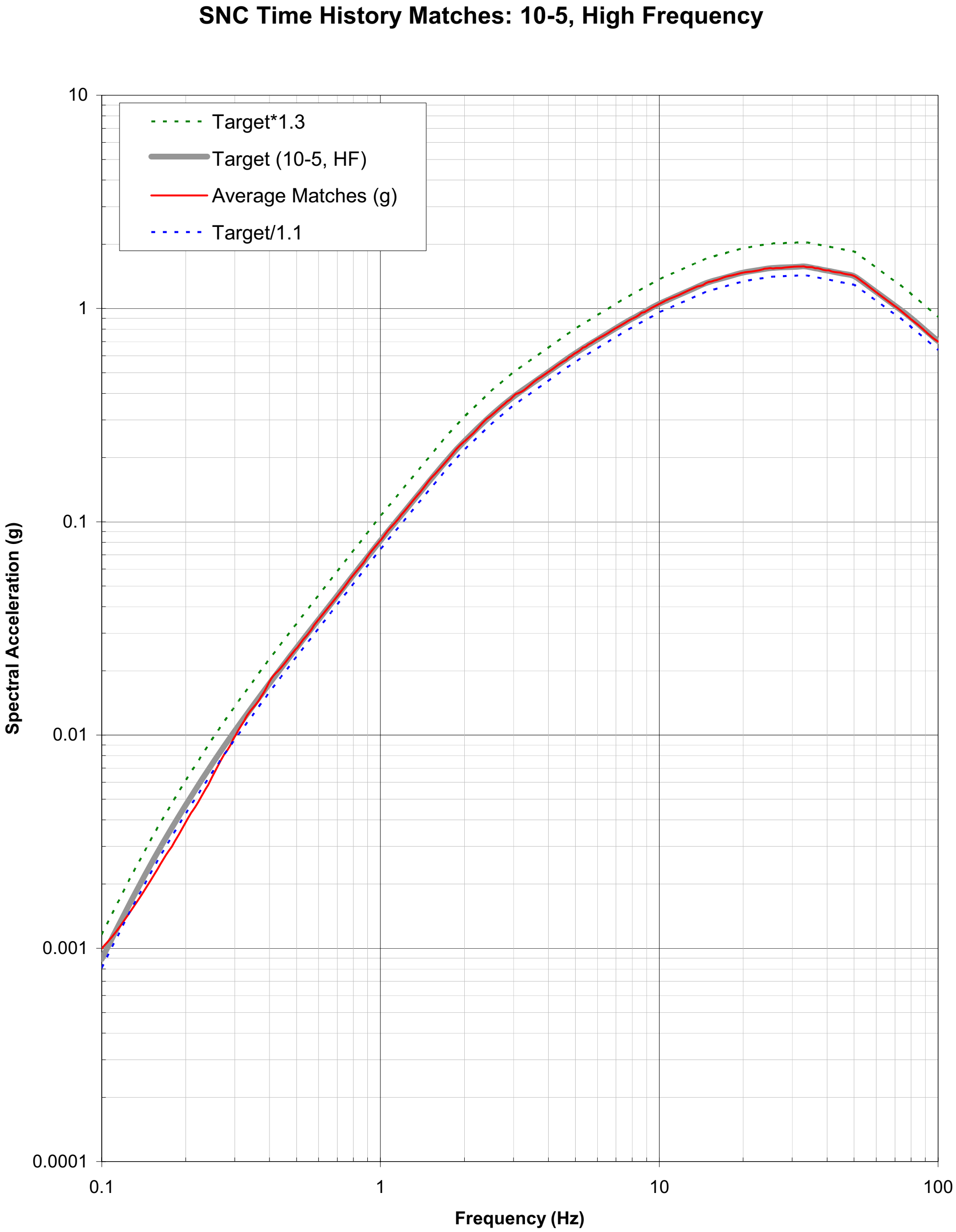


Figure 3. Comparison between the linear average of the suite of 30 spectrum compatible time histories (red line), target spectrum (thick gray line), target spectrum divided by 1.1 (dashed blue line), and target spectrum multiplied by 1.3 (dashed green line) for the high frequency 10^{-5} case.

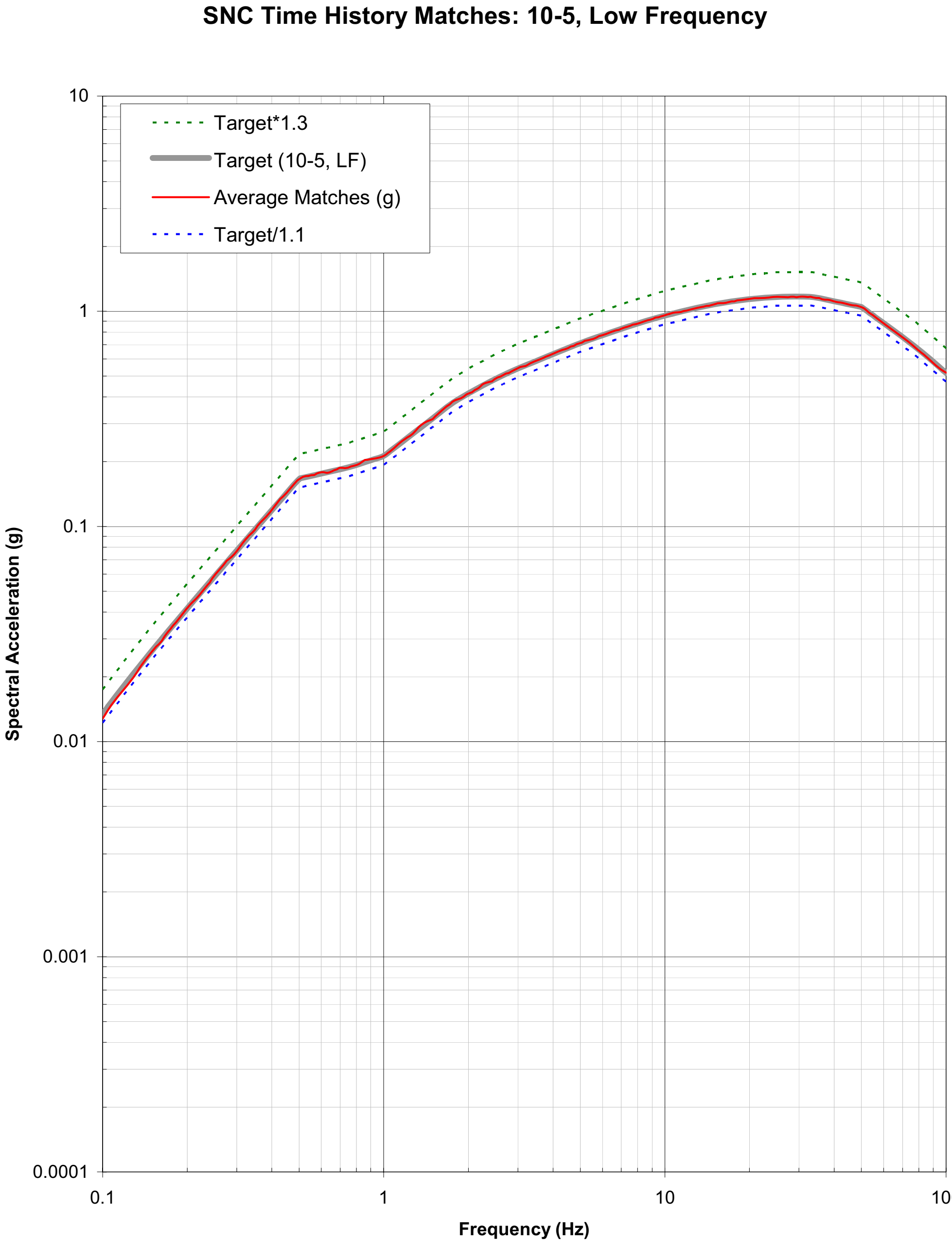


Figure 4. Comparison between the linear average of the suite of 30 spectrum compatible time histories (red line), target spectrum (thick gray line), target spectrum divided by 1.1 (dashed blue line), and target spectrum multiplied by 1.3 (dashed green line) for the low frequency 10^{-5} case.

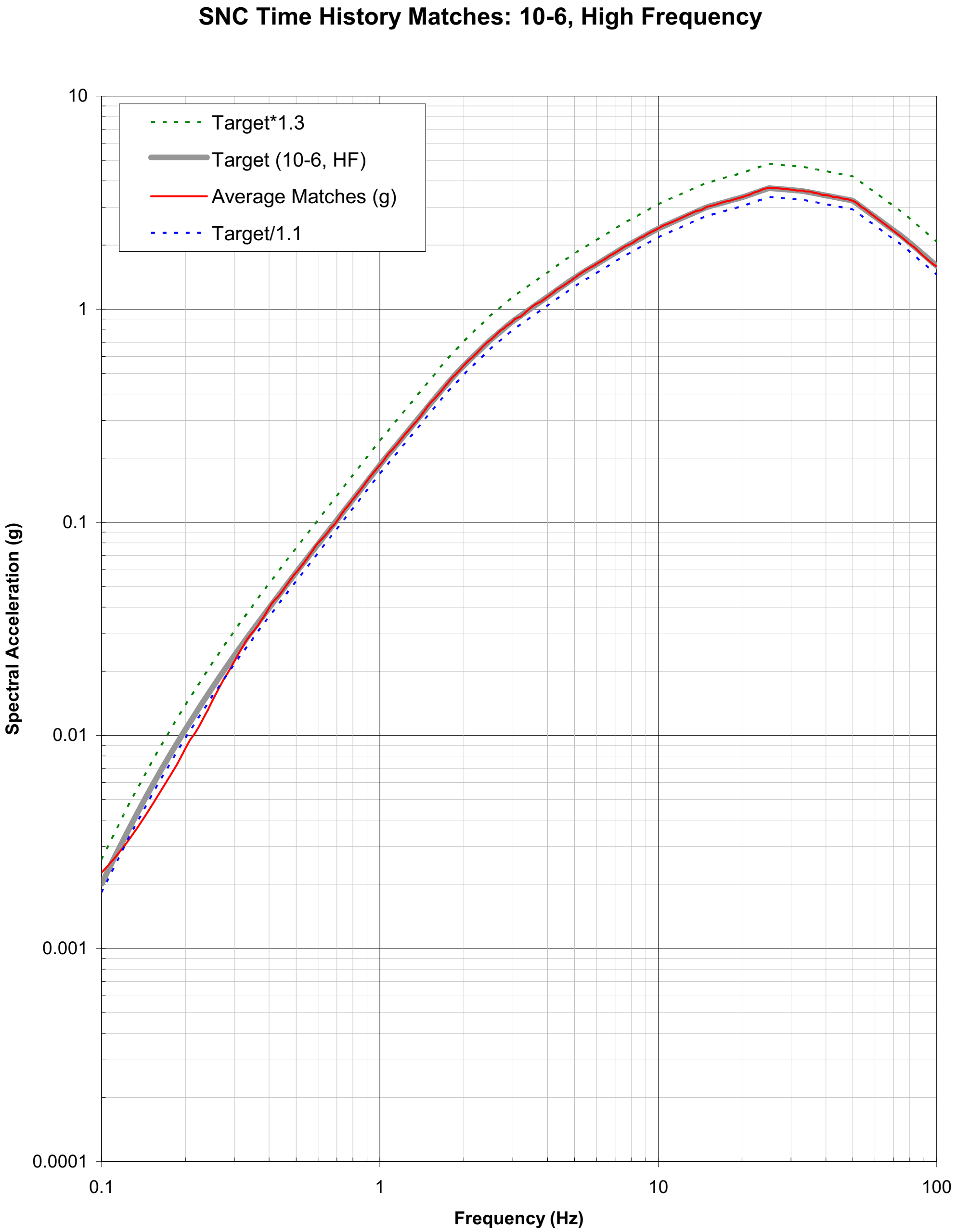


Figure 5. Comparison between the linear average of the suite of 30 spectrum compatible time histories (red line), target spectrum (thick gray line), target spectrum divided by 1.1 (dashed blue line), and target spectrum multiplied by 1.3 (dashed green line) for the high frequency 10^{-6} case.

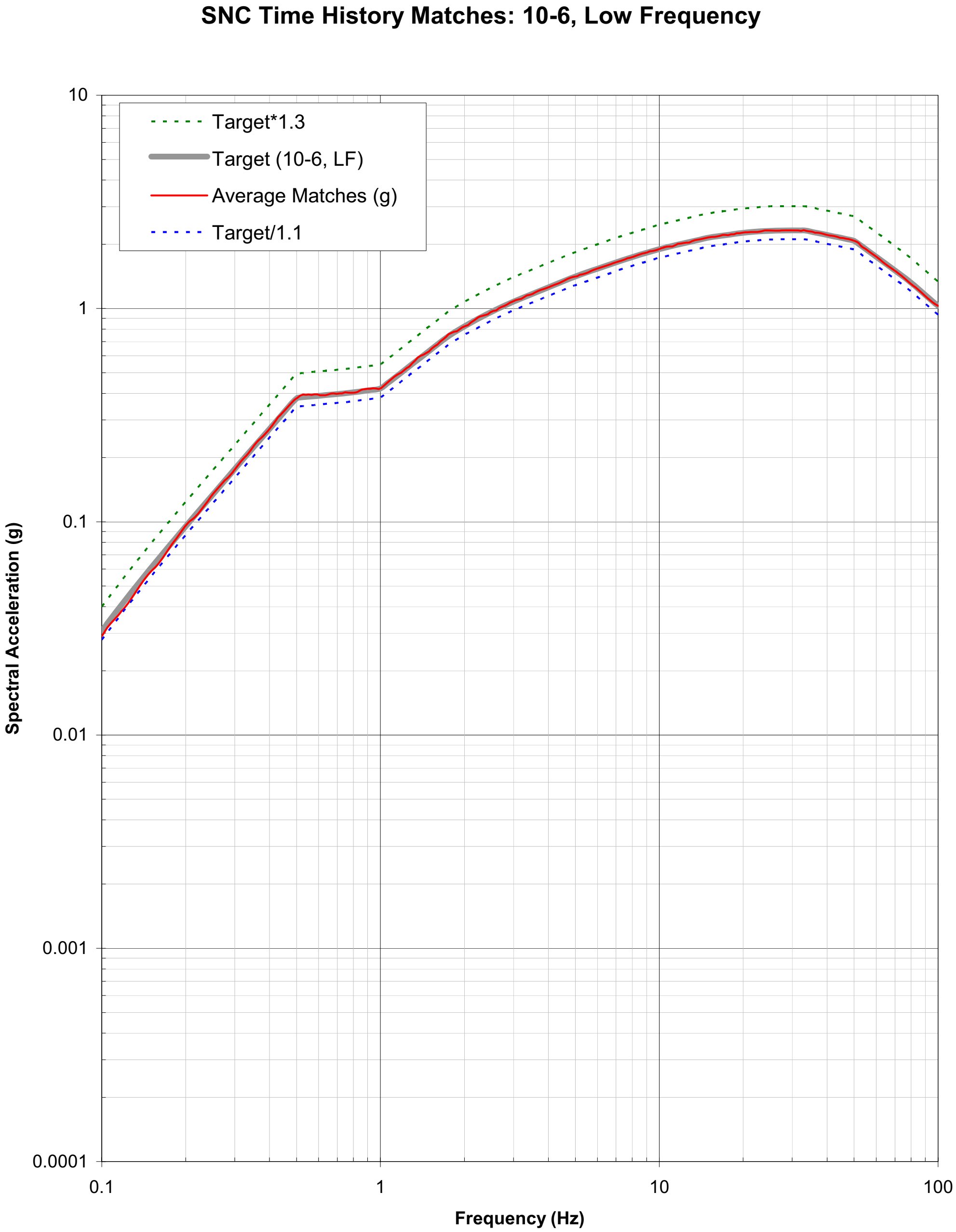


Figure 6. Comparison between the linear average of the suite of 30 spectrum compatible time histories (red line), target spectrum (thick gray line), target spectrum divided by 1.1 (dashed blue line), and target spectrum multiplied by 1.3 (dashed green line) for the low frequency 10^{-6} case.