NEXTera ENERGY DUANE ARNOLD

March 28, 2014

NG-14-0092
10 CFR 50.54(f)

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

Duane Arnold Energy Center
Docket No. 50-331
Renewed Op. License No. DPR-49

NextEra Energy Duane Arnold, LLC Seismic Hazard and Screening Report (CEUS Sites), Response to NRC Request for Information Pursuant to 10 CFR 50.54(f) Regarding Recommendation 2.1 of the Near-Term Task Force Review of Insights from the Fukushima Dai-ichi Accident

References:
1) NRC Letter, *Request for Information Pursuant to Title 10 of the Code of Federal Regulations 50.54(f) Regarding Recommendations 2.1, 2.3, and 9.3, of the Near-Term Task Force Review of Insights from the Fukushima Dai-ichi Accident*, dated March 12, 2012 (ML12073A348)
2) NEI Letter, *Proposed Path Forward for NTTF Recommendation 2.1: Seismic Reevaluations*, dated April 9, 2013 (ML13101A379)
3) NRC Letter, *Electric Power Research Institute Final Draft Report XXXXXX, "Seismic Evaluation Guidance: Augmented Approach for the Resolution of Fukushima Near-Term Task Force Recommendation 2.1: Seismic," as an Acceptable Alternative to the March 12, 2012, Information Request for Seismic Reevaluations*, dated May 7, 2013 (ML13106A331)
4) EPRI Report 1025287, *Seismic Evaluation Guidance, Screening, Prioritization and Implementation Details (SPID) for the Resolution of Fukushima Near-Term Task Force Recommendation 2.1: Seismic* (ML12333A170)
5) NRC Letter, *Endorsement of EPRI Final Draft Report 1025287, "Seismic Evaluation Guidance,"* dated February 15, 2013 (ML12319A074)

On March 12, 2012, the Nuclear Regulatory Commission (NRC) issued Reference 1 to all power reactor licensees and holders of construction permits in active or deferred status. Enclosure 1 of Reference 1 requested each addressee

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located in the Central and Eastern United States (CEUS) to submit a Seismic Hazard Evaluation and Screening Report within 1.5 years from the date of Reference 1.

In Reference 2, the Nuclear Energy Institute (NEI) requested NRC agreement to delay submittal of the final CEUS Seismic Hazard Evaluation and Screening Reports so that an update to the Electric Power Research Institute (EPRI) ground motion attenuation model could be completed and used to develop that information. NEI proposed that descriptions of subsurface materials and properties and base case velocity profiles be submitted to the NRC by September 12, 2013, with the remaining seismic hazard and screening information submitted by March 31, 2014. NRC agreed with that proposed path forward in Reference 3.

Reference 4 contains industry guidance and detailed information to be included in the Seismic Hazard Evaluation and Screening Report submittals. NRC endorsed this industry guidance in Reference 5.

The attached Seismic Hazard Evaluation and Screening Report for the Duane Arnold Energy Center contains the information described in Section 4 of Reference 4 in accordance with the schedule identified in Reference 2.

If you have any questions or require additional information, please contact Ken Putnam at 319-851-7238.

This letter makes no new commitments or changes to existing commitments.

I declare under penalty of perjury that the foregoing is true and correct.
Executed on March 28, 2014

Richard L. Anderson

Richard L. Anderson
Vice President, Duane Arnold Energy Center
NextEra Energy Duane Arnold, LLC

Enclosure

cc: Regional Administrator, USNRC, Region III
Resident Inspector, USNRC, Duane Arnold Energy Center
Project Manager, USNRC, Duane Arnold Energy Center

Attachment to NG-14-0092

<u>Seismic Hazard and Screening Report</u>
<u>For The Duane Arnold Energy Center</u>

34 pages follow

1.0 Introduction

Following the accident at the Fukushima Daiichi nuclear power plant resulting from the March 11, 2011, Great Tohoku Earthquake and subsequent tsunami, the NRC Commission established a Near Term Task Force (NTTF) to conduct a systematic review of NRC processes and regulations and to determine if the agency should make additional improvements to its regulatory system. The NTTF developed a set of recommendations intended to clarify and strengthen the regulatory framework for protection against natural phenomena. Subsequently, the NRC issued a 50.54(f) letter that requests information to assure that these recommendations are addressed by all U.S. nuclear power plants. The 50.54(f) letter requests that licensees and holders of construction permits under 10 CFR Part 50 reevaluate the seismic hazards at their sites against present-day NRC requirements. Depending on the comparison between the reevaluated seismic hazard and the current design basis, the result is either no further risk evaluation or the performance of a seismic risk assessment. Risk assessment approaches acceptable to the staff include a seismic probabilistic risk assessment (SPRA), or a seismic margin assessment (SMA). Based upon the risk assessment results, the NRC staff will determine whether additional regulatory actions are necessary.

This report provides the information requested in items (1) through (7) of the "Requested Information" section and Attachment 1 of the 50.54(f) letter pertaining to NTTF Recommendation 2.1 for the Duane Arnold Energy Center, located near the town of Palo in Linn County, Iowa. In providing this information, NextEra Energy Duane Arnold followed the guidance provided in the *Seismic Evaluation Guidance: Screening, Prioritization, and Implementation Details (SPID) for the Resolution of Fukushima Near-Term Task Force Recommendation 2.1: Seismic* (EPRI 1025287, 2012). The Augmented Approach, Seismic Evaluation Guidance: Augmented Approach for the Resolution of Fukushima Near-Term Task Force Recommendation 2.1: Seismic (EPRI 3002000704, 2013), has been developed as the process for evaluating critical plant equipment prior to performing the complete plant seismic risk evaluations.

The original geologic and seismic siting investigations for the Duane Arnold Energy Center included the following:

- A thorough review of pertinent geologic literature (published and unpublished) and interviews with university, state, and federal geologists.
- A geologic reconnaissance of the site and surrounding area and an interpretation of maps and aerial photographs.
- An investigation of subsurface soil, rock, and ground-water conditions by means of a test boring program, geophysical refraction surveys, and other related field studies.

The results of the geologic investigations concluded that there are no geologic features at the site or in the surrounding area that preclude the use of the site for a nuclear facility. The bedrock in the construction area is competent and will provide adequate foundation support for all major structures.

In response to the 50.54(f) letter and following the guidance provided in the SPID (EPRI 1025287, 2012), a seismic hazard reevaluation was performed. For screening purposes, a Ground Motion Response Spectrum (GMRS) was developed.

Based on the results of the screening evaluation, the Duane Arnold Energy Center screens in for a High Frequency Confirmation.

2.0 Seismic Hazard Reevaluation

Duane Arnold Energy Center is located adjacent to and west of the Cedar River, approximately 8 miles northwest of Cedar Rapids, Iowa. The site lies within the Central Stable Region of North America, an area in which the geologic structure is relatively simple. The region is characterized by a system of broad, circular to oblong erosional uplifts and sedimentary basins that include the Wisconsin and Ozark Domes and the Forest City, Michigan, and Illinois Basins. Minor structures, consisting primarily of northwest-southeast trending synclines and anticlines of low relief, are superimposed on these broader features in the region. Precambrian crystalline basement rocks lie some 2600 feet below the ground surface in the vicinity of the site. The crystalline basement complex is mantled by sedimentary rocks of Paleozoic age. The bedrock surface at the site ranges in depth from approximately 25 feet to more than 100 feet and is, in turn, overlain by glacial till and surficial deposits of clayey silt, sand, and gravel.

Faults have not been identified within the basement rocks or overlying sedimentary strata in the vicinity of the site. The closest known faults are located approximately 17 miles southeast of the site and 10 miles north of the site. The vertical displacement of these faults is estimated to be about 20 ft. Other known faults are located at significantly greater distances from the site. Faults in the region are believed to have been dormant since late Paleozoic time, at least 200 million years ago. The Paleozoic strata and overlying consolidated sediments within about 100 miles of the site are essentially undeformed. There are no geologic features at the site or in the surrounding area that preclude the use of the site for a nuclear facility. The bedrock in the construction area is competent and will provide adequate foundation support for all major structures. Remedial measures have been taken to ensure satisfactory performance of the bedrock in cavity areas.

Earthquake activity in historic time within 200 miles of the plant site has been moderate. Sources of major earthquakes in the central and eastern United States (CEUS) are distant, and have not had an appreciable effect at the site. The original investigation of historical seismic activity in the region indicated that a significant earthquake ground motion is not expected at the site during the life of the plant. NextEra Energy determined that for structures supported on bedrock and soil, peak ground accelerations of 0.12 g and 0.18 g, respectively, were conservative for use as the criteria response spectra.

2.1 Regional and Local Geology

The site lies in the northern portion of the interior Lowland Physiographic Province, within the Central Stable Region of North America, south of the Canadian Shield. The region is characterized by a basement complex of Precambrian crystalline rocks overlain by a varying thickness of Paleozoic sedimentary strata. The sedimentary rocks are of Pennsylvanian age or older. During the Mesozoic and Cenozoic Eras, this region generally was above sea level and subject to erosion rather than deposition, which accounts for the absence of younger formations. Minor accumulations of Cretaceous sediments exist in western Iowa and have been reported in portions of western Illinois. These deposits have not been identified in eastern Iowa. During the Pleistocene Epoch, the stable interior of the continent was covered by continental glaciers. These glaciers scoured the bedrock surface and subsequently covered much of the region with glacial drift.

Duane Arnold Energy Center is located adjacent to and west of the Cedar River, approximately 8 miles northwest of Cedar Rapids, Iowa. The bedrock strata immediately underlying the site are the Wapsipinicon and Gower Formations, of Middle Devonian and Upper Silurian age, respectively. A clay till containing some sand and gravel interspersed in the clay matrix directly overlies the bedrock surface. The till has, at various times, been described as both Kansan and Iowan, the latter being early Wisconsinan in age. The till thickness varies from 12 to 80 feet in the site area. The till thickness averages 20 feet in the plant area. Faults in the region are believed to have been dormant since late Paleozoic time, at least 200 million years ago. The Paleozoic strata and overlying consolidated sediments within about 100 miles of the site are essentially undeformed. No known faults exist within the basement rock or overlying sedimentary strata in the vicinity of the site. The closest known faults are located approximately 10 miles north of the site, and about 17 miles southeast of the site. These faults have only minor vertical displacements.

2.2 Probabilistic Seismic Hazard Analysis

2.2.1 Probabilistic Seismic Hazard Analysis Results

In accordance with the 50.54(f) letter and following the guidance in the SPID (EPRI 1025287, 2012), a probabilistic seismic hazard analysis (PSHA) was completed using the recently developed Central and Eastern United States Seismic Source Characterization (CEUS-SSC) for Nuclear Facilities (EPRI 1021097 and NUREG-2115, 2012) together with the updated EPRI Ground-Motion Model (GMM) for the CEUS (EPRI 3002000717, 2004, 2006, 2013). For the PSHA, a minimum moment magnitude cutoff of 5.0 was used, as specified in the 50.54(f) letter.

For the PSHA, the CEUS-SSC background seismic sources out to a distance of 400 miles (640 km) around Duane Arnold were included. This distance exceeds the 200 mile (320 km) recommendation contained in USNRC (2007) and was chosen for completeness. Background sources included in this site analysis are the following:

1. Illinois Basin Extended Basement (IBEB)
2. Mesozoic and younger extended prior – narrow (MESE-N)
3. Mesozoic and younger extended prior – wide (MESE-W)
4. Midcontinent-Craton alternative A (MIDC_A)
5. Midcontinent-Craton alternative B (MIDC_B)
6. Midcontinent-Craton alternative C (MIDC_C)

7. Midcontinent-Craton alternative D (MIDC_D)
8. Non-Mesozoic and younger extended prior – narrow (NMESE-N)
9. Non-Mesozoic and younger extended prior – wide (NMESE-W)
10. Reelfoot Rift (RR)
11. Reelfoot Rift including the Rough Creek Graben (RR-RCG)
12. Study region (STUDY_R)

For sources of large magnitude earthquakes, designated Repeated Large Magnitude Earthquake (RLME) sources in CEUS-SSC (2012), the following sources lie within 1,000 km of the site and were included in the analysis:

1. Commerce
2. Eastern Rift Margin Fault northern segment (ERM-N)
3. Eastern Rift Margin Fault southern segment (ERM-S)
4. Marianna
5. Meers
6. New Madrid Fault System (NMFS)
7. Wabash Valley

For each of the above background and RLME sources, the mid-continent version of the updated CEUS EPRI GMM was used.

2.2.2 Base Rock Seismic Hazard Curves

Consistent with the SPID (EPRI 1025287, 2012), base rock seismic hazard curves are not provided as the site amplification approach referred to as Method 3 has been used. Seismic hazard curves are shown below in Section 3 at the SSE control point elevation.

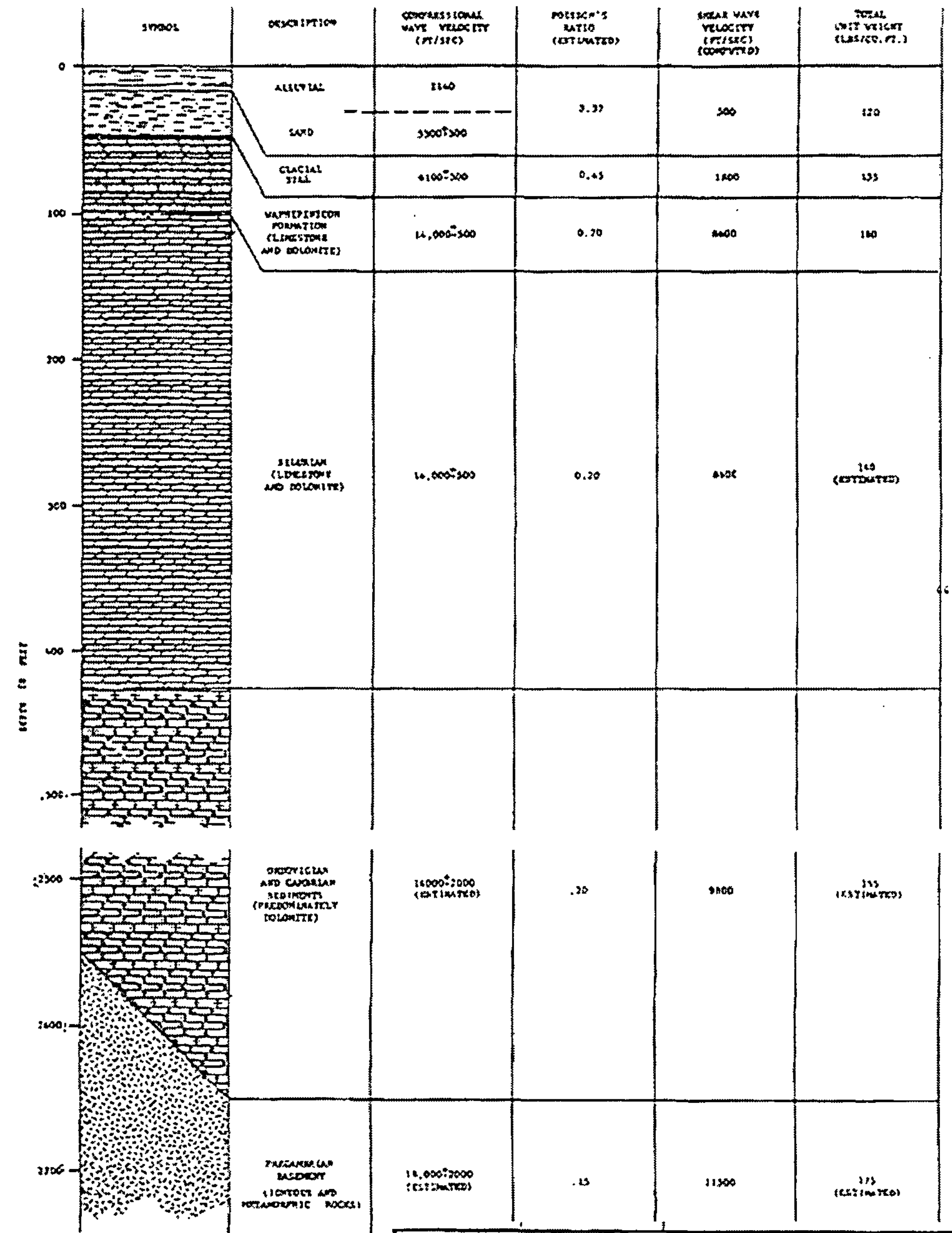
2.3 Site Response Evaluation

Following the guidance contained in Seismic Enclosure 1 of the 3/12/2012 50.54(f) Request for Information and in the SPID (EPRI 1025287, 2012) for nuclear power plant sites that are not sited on hard rock (defined as 2.83 km/sec), a site response analysis was performed for the Duane Arnold Energy Center.

2.3.1 Description of Subsurface Material

The Duane Arnold Energy Center site is located near Palo, in Linn County, Iowa. The basic information used to create the site geologic profile at the Duane Arnold Energy Center is shown in Table 2.3.1-1. This profile was developed using information documented in the UFSAR. The foundation of the Reactor Building is approximately 50 feet (15.2m) below grade, and this location was taken as the SSE Control Point. The SSE is located on firm limestone and dolomite rock of about 380 feet (116m) thickness. There are about 2,100 feet (640m) of firm Devonian and Cambrian sedimentary rocks which overlay Precambrian Basement. Table 2.3.1-1 shows the stratigraphic column, depths, unit weights and velocities based on P-wave refraction in the vicinity of the site. The S-wave velocities in Table 2.3.1-1 were calculated from the P-wave velocity and an assumed Poisson ratio.

TABLE 2.3.1-1 (Figure 2.5-9 of UFSAR)
Summary of Stratigraphic Profile and Geophysical Data for Duane Arnold Energy Center



DUANE ARNOLD ENERGY CENTER
IOWA ELECTRIC LIGHT & POWER COMPANY
UPDATED FINAL SAFETY ANALYSIS REPORT

Stratigraphic Section Showing
Geophysical Data

Figure 2.5-9

2.3.2 Development of Base Case Profiles and Nonlinear Material Properties

Table 2.3.1-1 shows the recommended shear-wave velocities and unit weights along with depths and corresponding stratigraphy. The SSE control point is at a depth of about 50 feet (15m) at the top of a limestone and dolomite formation with a calculated constant shear-wave velocity of 8,600 ft/s (2621 m/s). Shear-wave velocities were calculated from compressional-wave velocity and an assumed Poisson ratio. From Table 2.3.1-1, with the SSE at a depth of 50 feet (15m), the depth below the SSE to Precambrian Basement (hard rock) was assumed to be either 380 feet (116m) at the top of Ordovician or 2,500 feet (762 m).

Based on the uncertainty in shear-wave velocities due to the lack of direct measurements, vintage of the P-wave velocity measurements and an assumed Poisson ratio, a scale factor of 1.57 was adopted to reflect upper and lower range base-cases. The scale factor of 1.57 reflects a $\sigma_{\mu ln}$ of about 0.35 based on the SPID (EPRI 1025287, 2012) 10^{th} and 90^{th} fractiles which implies a 1.28 scale factor on σ_{μ}.

Using the shear-wave velocities specified in Table 2.3.1-1, three base-profiles were developed using the scale factor of 1.57. The specified shear-wave velocities were taken as the mean or best estimate base-case profile (P1) with lower and upper range base-cases profiles P2 and P3 respectively. Profile P1, mean base-case, extended to hard rock conditions at a depth (below the SSE) of 380 feet (112m). Profile P2, lower range base-cases, extended to hard rock conditions at a depth (below the SSE) of 2,500 feet (762m). Profiles P1 and P2 are both randomized ± 750 feet (± 2290\m). Profile P3, upper range base-case, represents hard rock conditions at the surface of the site. The base-case profiles (P1, P2, and P3) are shown in Figure 2.3.2-1 and listed in Table 2.3.2-1. The depth randomization (for P1 and P2) reflects ± 30% of the depth and was included to provide a realistic broadening of the fundamental resonance at deep sites rather than reflect actual random variations to basement shear-wave velocities across a footprint.

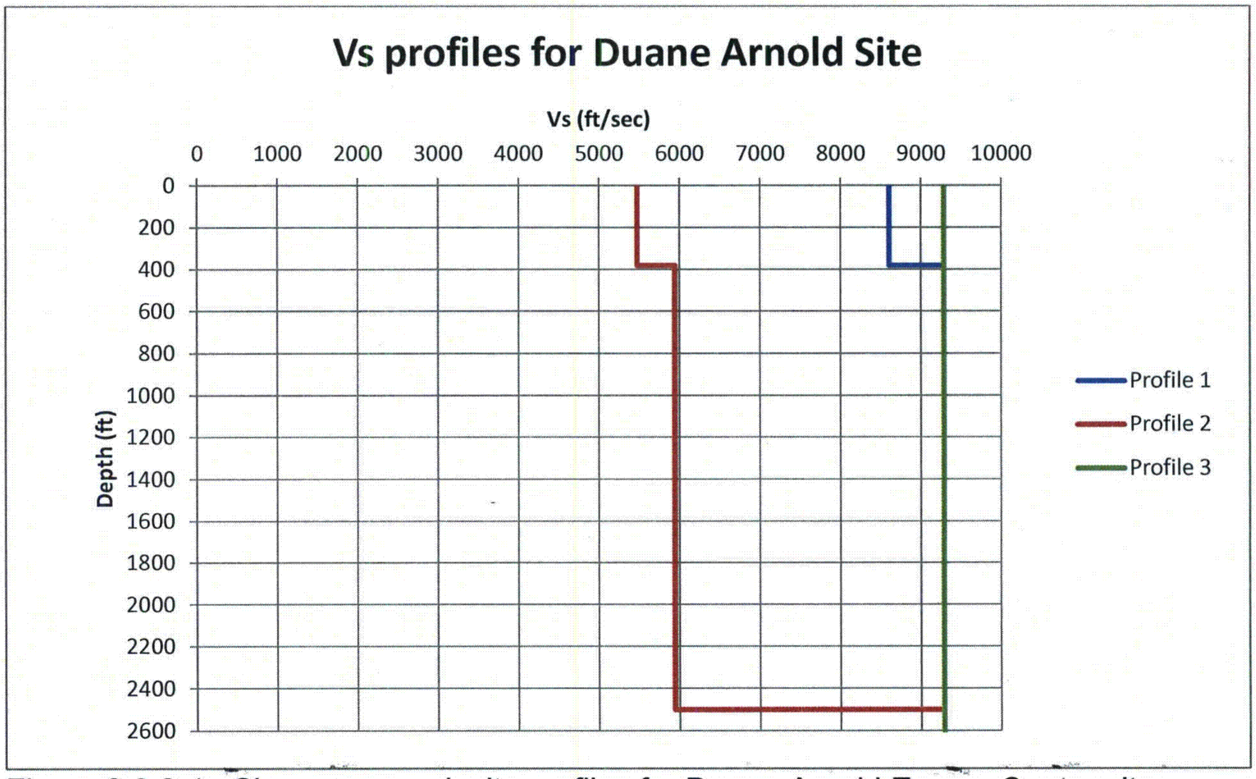


Figure 2.3.2-1. Shear-wave velocity profiles for Duane Arnold Energy Center site

Table 2.3.2-1
Layer thicknesses, depths, and shear-wave velocities (Vs) for 3 profiles, Duane Arnold

Profile 1			Profile 2			Profile 3		
Thick-ness (ft)	depth (ft)	Vs(ft/s)	Thick-ness (ft)	depth (ft)	Vs(ft/s)	Thick-ness (ft)	depth (ft)	Vs(ft/s)
	0	8600		0	5477		0	9285
10.0	10.0	8600	10.0	10.0	5477	10.0	10.0	9285
10.0	20.0	8600	10.0	20.0	5477	10.0	20.0	9285
10.0	30.0	8600	10.0	30.0	5477	10.0	30.0	9285
10.0	40.0	8600	10.0	40.0	5477	10.0	40.0	9285
10.0	50.0	8600	10.0	50.0	5477	10.0	50.0	9285
10.0	60.0	8600	10.0	60.0	5477	10.0	60.0	9285
10.0	70.0	8600	10.0	70.0	5477	10.0	70.0	9285
10.0	80.0	8600	10.0	80.0	5477	10.0	80.0	9285
10.0	90.0	8600	10.0	90.0	5477	10.0	90.0	9285
10.0	100.0	8600	10.0	100.0	5477	10.0	100.0	9285
10.0	110.0	8600	10.0	110.0	5477	10.0	110.0	9285
10.0	120.0	8600	10.0	120.0	5477	10.0	120.0	9285
10.0	130.0	8600	10.0	130.0	5477	10.0	130.0	9285
10.0	140.0	8600	10.0	140.0	5477	10.0	140.0	9285
10.0	150.0	8600	10.0	150.0	5477	10.0	150.0	9285
10.0	160.0	8600	10.0	160.0	5477	10.0	160.0	9285
10.0	170.0	8600	10.0	170.0	5477	10.0	170.0	9285
10.0	180.0	8600	10.0	180.0	5477	10.0	180.0	9285
10.0	190.0	8600	10.0	190.0	5477	10.0	190.0	9285
10.0	200.0	8600	10.0	200.0	5477	10.0	200.0	9285
10.0	210.0	8600	10.0	210.0	5477	10.0	210.0	9285
10.0	220.0	8600	10.0	220.0	5477	10.0	220.0	9285
10.0	230.0	8600	10.0	230.0	5477	10.0	230.0	9285
10.0	240.0	8600	10.0	240.0	5477	10.0	240.0	9285
10.0	250.0	8600	10.0	250.0	5477	10.0	250.0	9285
10.0	260.0	8600	10.0	260.0	5477	10.0	260.0	9285
10.0	270.0	8600	10.0	270.0	5477	10.0	270.0	9285
10.0	280.0	8600	10.0	280.0	5477	10.0	280.0	9285
10.0	290.0	8600	10.0	290.0	5477	10.0	290.0	9285
10.0	300.0	8600	10.0	300.0	5477	10.0	300.0	9285
10.0	310.0	8600	10.0	310.0	5477	10.0	310.0	9285
10.0	320.0	8600	10.0	320.0	5477	10.0	320.0	9285
10.0	330.0	8600	10.0	330.0	5477	10.0	330.0	9285
10.0	340.0	8600	10.0	340.0	5477	10.0	340.0	9285
10.0	350.0	8600	10.0	350.0	5477	10.0	350.0	9285
10.0	360.0	8600	10.0	360.0	5477	10.0	360.0	9285
10.0	370.0	8600	10.0	370.0	5477	10.0	370.0	9285

10.0	380.0	8600	10.0	380.0	5477	10.0	380.0	9285
5.9	385.9	9285	5.9	385.9	5942	5.9	385.9	9285
26.0	412.0	9285	26.0	412.0	5942	26.0	412.0	9285
26.0	438.0	9285	26.0	438.0	5942	26.0	438.0	9285
26.0	464.0	9285	26.0	464.0	5942	26.0	464.0	9285
26.0	490.0	9285	26.0	490.0	5942	26.0	490.0	9285
26.0	516.0	9285	10.9	500.9	5942	10.9	500.9	9285
38.4	554.4	9285	53.6	554.4	5942	53.6	554.4	9285
38.4	592.9	9285	38.4	592.9	5942	38.4	592.9	9285
38.4	631.3	9285	38.4	631.3	5942	38.4	631.3	9285
38.4	669.7	9285	38.4	669.7	5942	38.4	669.7	9285
38.4	708.1	9285	38.4	708.1	5942	38.4	708.1	9285
57.8	766.0	9285	57.8	766.0	5942	57.8	766.0	9285
106.2	872.2	9285	106.2	872.2	5942	106.2	872.2	9285
151.3	1023.5	9285	151.3	1023.5	5942	151.3	1023.5	9285
164.0	1187.5	9285	164.0	1187.5	5942	164.0	1187.5	9285
164.0	1351.6	9285	164.0	1351.6	5942	164.0	1351.6	9285
164.0	1515.6	9285	164.0	1515.6	5942	164.0	1515.6	9285
164.0	1679.7	9285	164.0	1679.7	5942	164.0	1679.7	9285
164.0	1843.7	9285	164.0	1843.7	5942	164.0	1843.7	9285
164.0	2007.7	9285	164.0	2007.7	5942	164.0	2007.7	9285
164.0	2171.8	9285	164.0	2171.8	5942	164.0	2171.8	9285
164.0	2335.8	9285	164.0	2335.8	5942	164.0	2335.8	9285
164.0	2499.9	9285	164.0	2499.9	5942	164.0	2499.9	9285
3280.8	5780.7	9285	3280.8	5780.7	9285	3280.8	5780.7	9285

2.3.2.1 Shear Modulus and Damping Curves

No site-specific nonlinear dynamic material properties were determined for the firm rock materials in the initial siting of the Duane Arnold Energy Center. The rock material over the upper 500 ft (152m) was assumed to have behavior that could be modeled as either linear or non-linear. To represent this potential for either case in the upper 500 ft of firm rock at the Duane Arnold Energy Center site, two sets of shear modulus reduction and hysteretic damping curves were used. Consistent with the SPID (EPRI 1025287, 2012), the EPRI rock curves (model M1) were considered to be appropriate to represent the upper range nonlinearity likely in the materials at this site and linear analyses (model M2) was assumed to represent an equally plausible alternative rock response across loading level. For the linear analyses, the low strain damping from the EPRI rock curves were used as the constant damping values in the upper 500 ft.

2.3.2.2 Kappa

Base-case kappa estimates were determined using Section B-5.1.3.1 of the SPID (EPRI 1025287, 2012) for a firm CEUS rock site. Kappa for a firm rock site with at least 3,000 ft (1 km) of sedimentary rock may be estimated from the average S-wave velocity over the upper 100 ft (V_{s100}) of the subsurface profile while for a site with less than 3,000 ft (1 km) of firm rock, kappa may be estimated with a Q_s of 40 below 500 ft combined with the low strain damping from the EPRI rock curves and an additional kappa of 0.006s for the underlying hard rock. For the Duane Arnold Energy Center site, with firm rock of thickness 380 ft (116 m for P1), 2,500 ft (762 m for P2) and 0 ft (0m for P3), the kappa contributions from the profiles were 0.002s, 0.014s and 0.000s, respectively. The total kappa values, after adding the hard reference rock value of 0.006s, were 0.008s, 0.020s, and 0.006s (Table 2.3.2-2). The range in kappa about the best estimate base-case value of 0.008s (profile P1) was considered sufficient to adequately reflect epistemic uncertainty in low strain damping (kappa) for the profile. The suite of kappa estimates and associated weights are listed in Table 2.3.2-2.

Table 2.3.2-2
Kappa Values and Weights Used for Site Response Analyses

Velocity Profile	Kappa(s)
P1	0.008
P2	0.020
P3	0.006
	Weights
P1	0.4
P2	0.3
P3	0.3
G/G_{max} and Hysteretic Damping Curves	
M1	0.5
M2	0.5

2.3.3 Randomization of Base Case Profiles

To account for the aleatory variability in material properties that is expected to occur across a site at the scale of a typical nuclear facility, variability in the assumed shear-wave velocity profiles has been incorporated in the site response calculations. For the Duane Arnold Energy Center site, random shear wave velocity profiles were developed from the base case profiles as shown in Figure 2.3.2-1. Consistent with the discussion in Appendix B of the SPID (EPRI 1025287, 2012), the velocity randomization procedure made use of random field models which describe the statistical correlation between layering and shear wave velocity. The default randomization parameters developed in Toro (1997) for USGS "A" site conditions were used for this site. Thirty random velocity profiles were generated for each base case profile. These random velocity profiles were generated using a natural log standard deviation of 0.25 over the upper 50 ft and 0.15 below that depth. As specified in the SPID (EPRI 1025287, 2012), correlation of shear wave velocity between layers was modeled using the USGS "A" correlation model. In the correlation model, a limit of +/- 2 standard deviations about the median value in each layer was assumed for the limits on random velocity fluctuations. All random velocities were limited to be less than or equal to 9830 ft/sec.

2.3.4 Input Spectra

Consistent with the guidance in Appendix B of the SPID (EPRI 1025287, 2012), input Fourier amplitude spectra were defined for a single representative earthquake magnitude using two different assumptions regarding the shape of the seismic source spectrum (single-corner and double-corner.) A range of 11 different input amplitudes (median peak ground accelerations (PGA) ranging from 0.01 to 1.5 g) were used in the site response analyses. The characteristics of the seismic source and upper crustal attenuation properties assumed for the analysis of the Duane Arnold Energy Center site were the same as those identified in Tables B-4, B-5, B-6 and B-7of the SPID (EPRI 1025287, 2012) as appropriate for typical CEUS sites.

2.3.5 Methodology

To perform the site response analyses for the Duane Arnold Energy Center, a random vibration theory (RVT) approach was employed. This process utilizes a simple, efficient approach for computing site-specific amplification functions and is consistent with existing NRC guidance and the SPID (EPRI 1025287, 2012). The guidance contained in Appendix B of the SPID (EPRI 1025287, 2012) on incorporating epistemic uncertainty in shear-wave velocities, kappa, non-linear dynamic properties and source spectra for plants with limited at-site information was followed for the Duane Arnold Energy Center site.

2.3.6 Amplification Functions

The results of the site response analysis consist of amplification factors (5% damped pseudo absolute response spectra) which describe the amplification (or de-amplification) of hard reference rock motion as a function of frequency and input reference rock amplitude. The amplification factors are represented in terms of a median amplification value and an associated standard deviation (sigma) for each oscillator frequency and input rock amplitude. Consistent with the SPID (EPRI 1025287, 2012) a minimum median amplification value of 0.5 was employed in the present analysis. Figure 2.3.6-1 illustrates the median and +/- 1 standard deviation in the predicted amplification factors developed for the eleven loading levels parameterized by the median reference (hard rock) peak acceleration (0.01g to 1.50g) for profile P1 and EPRI (1993) rock G/G_{max} and hysteretic damping curves. The variability in the amplification factors results from variability in shear-wave velocity, depth to hard rock, and modulus reduction and hysteretic damping curves. To illustrate the effects of nonlinearity at the Duane Arnold Energy Center firm rock site, Figure 2.3.6-2 shows the corresponding amplification factors developed with linear site response analyses (model M2). Figures 2.3.6-1 and Figure 2.3.6-2 respectively show only a minor difference for all frequencies and loading levels. Tabulated values of the amplification factors are provided in Appendix A.

Figure 2.3.6-1. Example suite of amplification factors (5% damping pseudo absolute acceleration spectra) developed for the mean base-case profile (P1), EPRI rock modulus reduction and hysteretic damping curves (model M1), and base-case kappa (K1) at eleven loading levels of hard rock median peak acceleration values from 0.01g to 1.50g. **M** 6.5 and single-corner source model (SPID, EPRI 1025287, 2012).

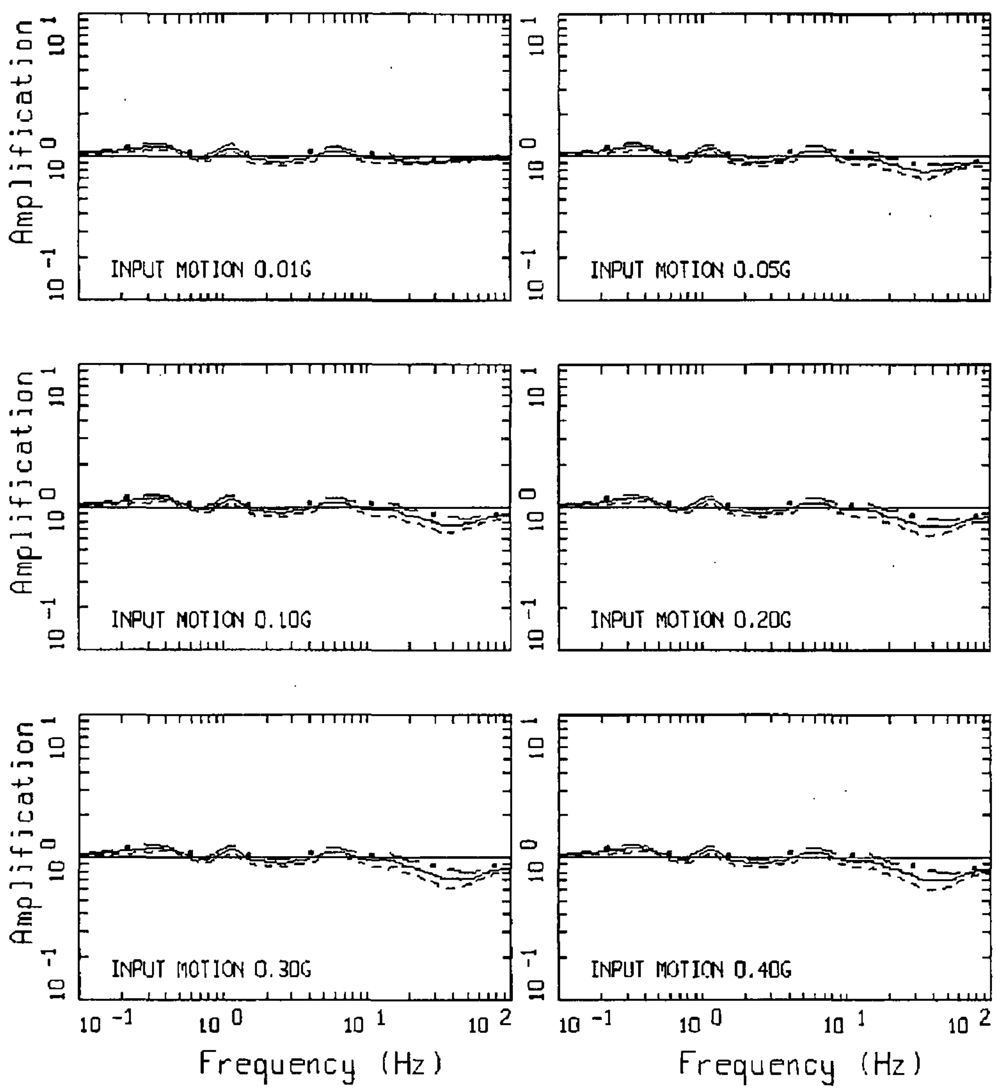


Figure 2.3.6-1. (continued) Example suite of amplification factors (5% damping pseudo absolute acceleration spectra) developed for the mean base-case profile (P1), EPRI rock modulus reduction and hysteretic damping curves (model M1), and base-case kappa (K1) at eleven loading levels of hard rock median peak acceleration values from 0.01g to 1.50g. **M** 6.5 and single-corner source model (SPID, EPRI 1025287, 2012).

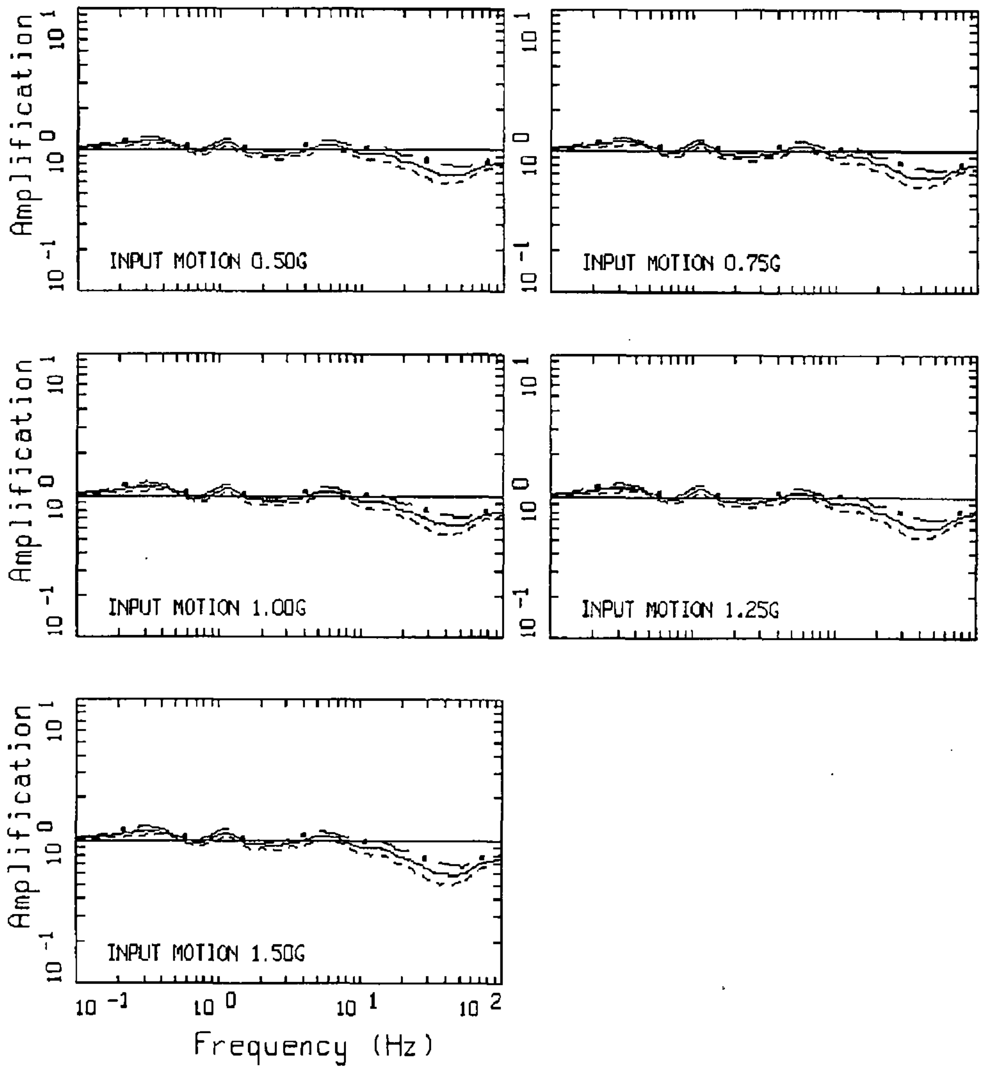


Figure 2.3.6-2. Example suite of amplification factors (5% damping pseudo absolute acceleration spectra) developed for the mean base-case profile (P1), linear site response (model M2), and base-case kappa (K1) at eleven loading levels of hard rock median peak acceleration values from 0.01g to 1.50g. **M** 6.5 and single-corner source model (SPID, EPRI 1025287, 2012)

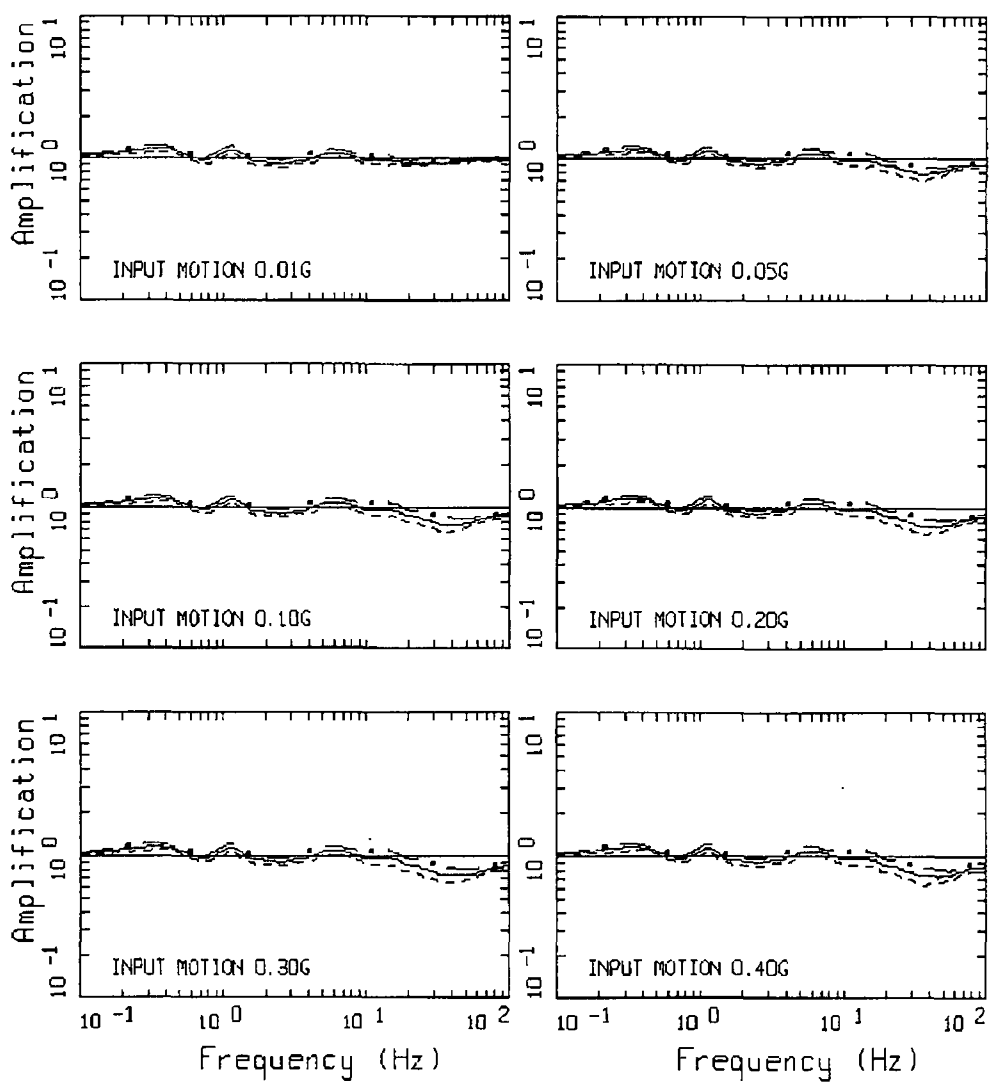
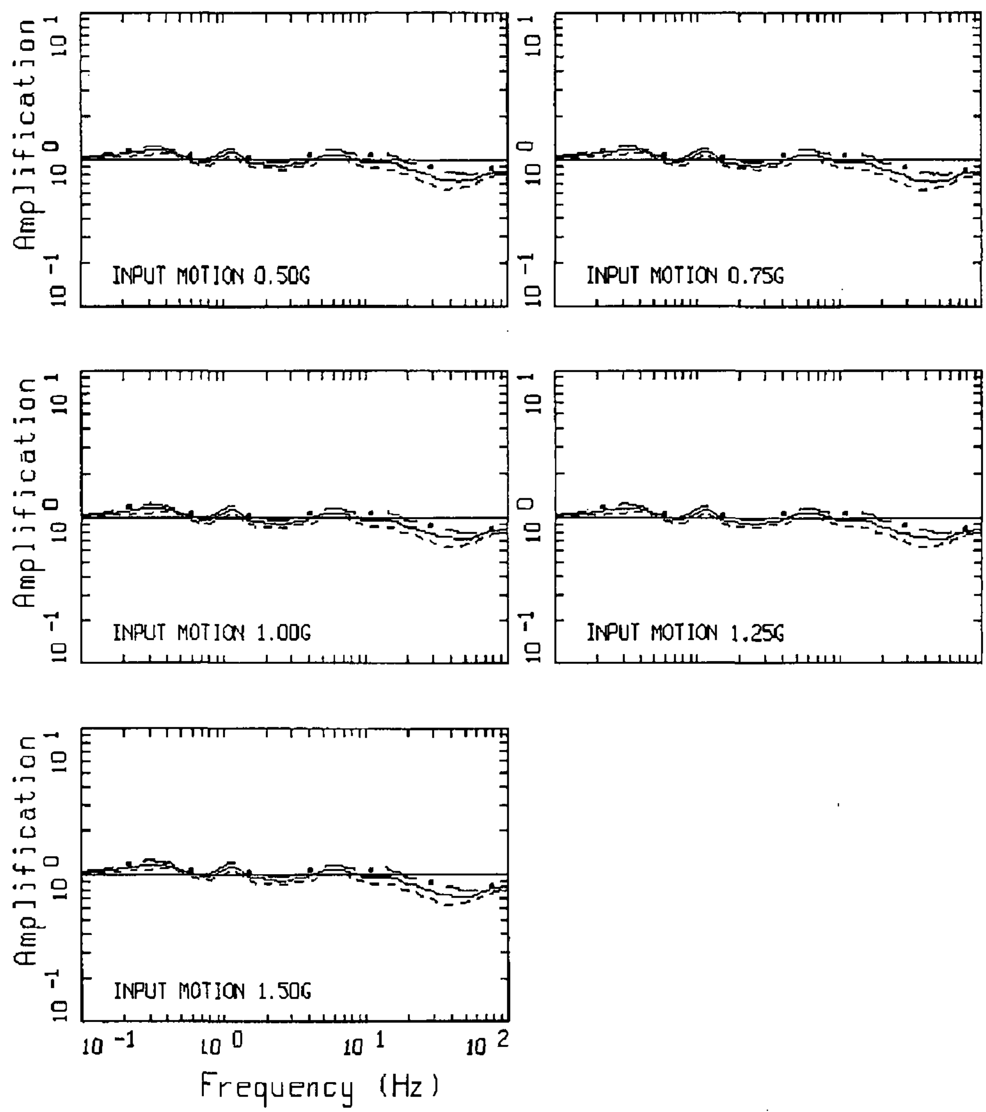


Figure 2.3.6-2. (continued) Example suite of amplification factors (5% damping pseudo absolute acceleration spectra) developed for the mean base-case profile (P1), linear site response (model M2), and base-case kappa (K1) at eleven loading levels of hard rock median peak acceleration values from 0.01g to 1.50g. **M** 6.5 and single-corner source model (SPID, EPRI 1025287, 2012)



2.3.7 Control Point Seismic Hazard Curves

The procedure to develop probabilistic site-specific control point hazard curves used in the present analysis follows the methodology described in Section B-6.0 of the SPID (EPRI 1025287, 2012). This procedure (referred to as Method 3) computes a site-specific control point hazard curve for a broad range of spectral accelerations given the site-specific bedrock hazard curve and site-specific estimates of soil or soft-rock response and associated uncertainties. This process is repeated for each of the seven specified oscillator frequencies. The dynamic response of the materials below the control point was represented by the frequency- and amplitude-dependent amplification functions (median values and standard deviations) developed and described in the previous section. The resulting control point mean hazard curves for the Duane Arnold Energy Center site are shown in Figure 2.3.7-1 for the seven oscillator frequencies for which the GMM is defined. Tabulated values of the site response amplification functions and control point hazard curves are provided in Appendix A.

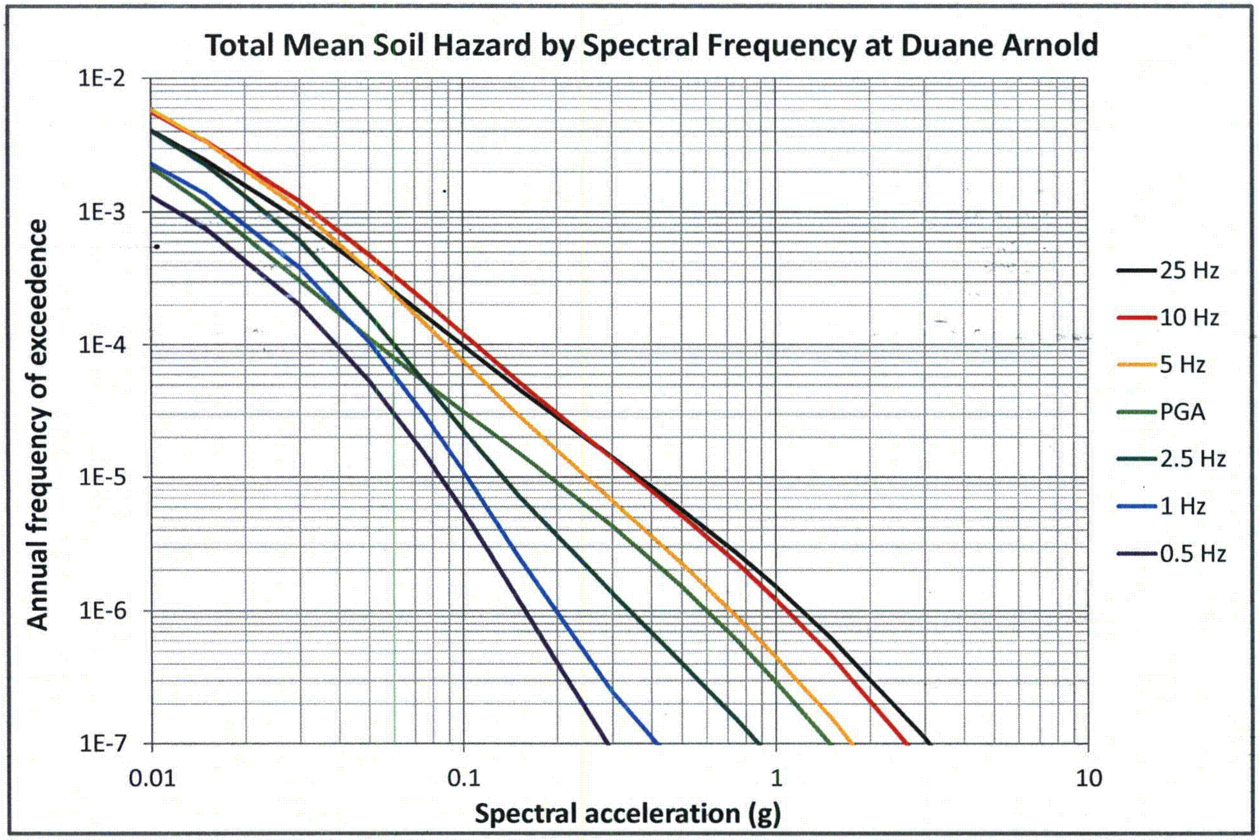


Figure 2.3.7-1. Control point mean hazard curves for spectral frequencies of 0.5, 1, 2.5, 5, 10, 25 and 100 Hz at Duane Arnold.

2.4 Control Point Response Spectra

The control point hazard curves described above have been used to develop uniform hazard response spectra (UHRS) and the ground motion response spectrum (GMRS).

The UHRS were obtained through linear interpolation in log-log space to estimate the spectral acceleration at each oscillator frequency for the 1E-4 and 1E-5 per year hazard levels. Table 2.4-1 shows the UHRS and GMRS spectral accelerations.

Table 2.4-1. UHRS and GMRS for Duane Arnold.

Freq. (Hz)	10^{-4} UHRS (g)	10^{-5} UHRS (g)	GMRS (g)
100	5.31E-02	1.89E-01	8.81E-02
90	5.35E-02	1.90E-01	8.85E-02
80	5.41E-02	1.92E-01	8.95E-02
70	5.52E-02	1.97E-01	9.17E-02
60	5.77E-02	2.11E-01	9.78E-02
50	6.42E-02	2.50E-01	1.14E-01
40	7.54E-02	3.01E-01	1.37E-01
35	8.20E-02	3.23E-01	1.47E-01
30	9.03E-02	3.46E-01	1.59E-01
25	9.93E-02	3.64E-01	1.69E-01
20	1.05E-01	3.73E-01	1.74E-01
15	1.12E-01	3.81E-01	1.79E-01
12.5	1.12E-01	3.73E-01	1.76E-01
10	1.10E-01	3.55E-01	1.68E-01
9	1.07E-01	3.36E-01	1.60E-01
8	1.04E-01	3.18E-01	1.52E-01
7	1.00E-01	3.00E-01	1.44E-01
6	9.59E-02	2.77E-01	1.35E-01
5	8.85E-02	2.48E-01	1.21E-01
4	7.99E-02	2.07E-01	1.03E-01
3.5	7.48E-02	1.86E-01	9.29E-02
3	6.75E-02	1.60E-01	8.06E-02
2.5	6.00E-02	1.34E-01	6.84E-02
2	5.95E-02	1.30E-01	6.66E-02
1.5	5.43E-02	1.15E-01	5.94E-02
1.25	5.39E-02	1.12E-01	5.81E-02
1	5.07E-02	1.03E-01	5.36E-02
0.9	4.82E-02	9.88E-02	5.14E-02
0.8	4.60E-02	9.54E-02	4.95E-02
0.7	4.38E-02	9.20E-02	4.76E-02
0.6	4.16E-02	8.85E-02	4.57E-02
0.5	3.92E-02	8.45E-02	4.35E-02
0.4	3.13E-02	6.76E-02	3.48E-02
0.35	2.74E-02	5.92E-02	3.04E-02
0.3	2.35E-02	5.07E-02	2.61E-02
0.25	1.96E-02	4.23E-02	2.17E-02
0.2	1.57E-02	3.38E-02	1.74E-02
0.15	1.17E-02	2.54E-02	1.30E-02
0.125	9.79E-03	2.11E-02	1.09E-02
0.1	7.83E-03	1.69E-02	8.69E-03

The 1E-4 and 1E-5 UHRS are used to compute the GMRS at the control point and are shown in Figure 2.4-1.

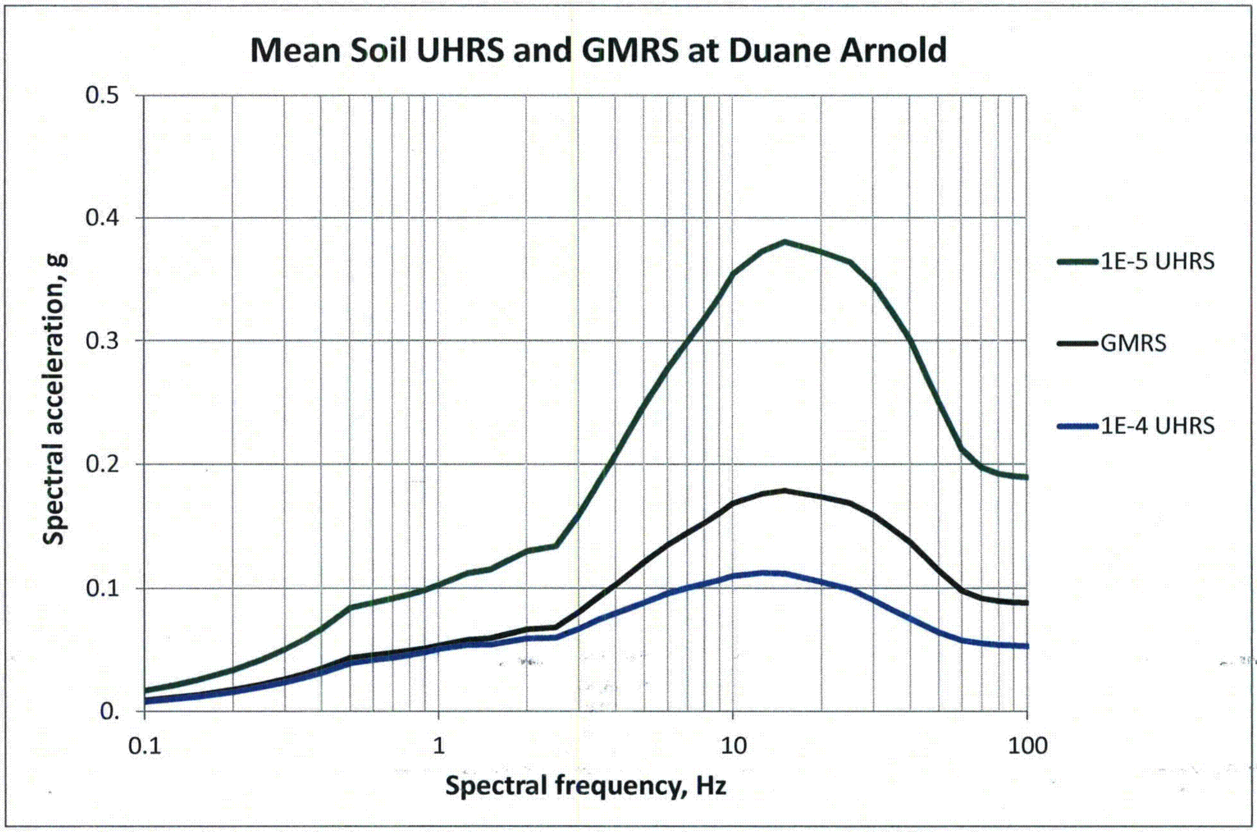


Figure 2.4-1. Plots of 1E-4 and 1E-5 uniform hazard spectra and GMRS at control point for Duane Arnold (5%-damped response spectra).

3.0 Plant Design Basis

The design basis for the Duane Arnold Energy Center is identified in the Updated Safety Analysis Report (Reference 1). An evaluation has been made of the degree of ground motion which is remotely possible, considering both seismic history and geologic structure. The critical structures are designed for safe shutdown due to the appropriate ground accelerations at foundation level. In developing the SSE factors, it has been considered that there is a history of minor to moderate earthquake activity in the region, which has not been related to known tectonic features.

3.1 SSE Description of Spectral Shape

The Duane Arnold Energy Center buildings were seismically analyzed by means of time history method by modal superposition. One earthquake acceleration time history was developed for use as the input motion at bedrock. Building forces and accelerations were derived from the time history analysis for all buildings. The same time history was used to generate the in-structure response spectra for qualifying equipment and distributed electrical and mechanical systems including piping. The Reactor Building SSE criteria response spectrum at bedrock is based on a Housner spectrum shape. For other buildings founded on soil, like the Control Building, the SSE criteria response spectrum shape is based on a smoothed 1952 Taft response spectrum. The buildings supported on soil were modeled with equivalent soil springs between the base of the model and the building foundation to account for soil-structure interaction effects. This allows the bedrock motion to be the input for the seismic analysis with amplification effects being directly calculated. The time history analysis produced spectra that were conservative for both the rock and soil supported buildings.

The control point for the Duane Arnold Energy Center is the foundation of the Reactor Building at the top of the bedrock. This is also the control point for the buildings founded on soil including the Control Building. The single time history used as the bedrock motion for the seismic excitation analyses was a modified time history based on the north-south component of the 1940 El Centro earthquake. The time history was developed to be conservative relative to the criteria response spectra.

The response spectrum associated with the modified El Centro time history is the one used for the comparison with the GMRS since it represents the input motion used to seismically analyze all of the buildings and to generate the in-structure response spectra used to seismically analyze the systems and equipment at Duane Arnold Energy Center.

The SSE is defined in terms of a PGA and a design response spectrum. Table 3.1-1 shows the spectral acceleration values as a function of frequency for the 0.12 g as the anchor point for the 5% damped horizontal SSE at the bedrock.

Table 3.1-1.
SSE for Bedrock

Frequency (Hz)	SSE (g)
100.00	0.120
90.00	0.120
80.00	0.120
70.00	0.120
60.00	0.120
50.00	0.120
40.00	0.120
35.00	0.120
30.00	0.120
25.00	0.140
20.00	0.174
15.00	0.200
12.50	0.210
10.00	0.224
9.00	0.230
8.00	0.234
7.00	0.238
6.00	0.256
5.00	0.280
4.00	0.306
3.50	0.318
3.00	0.320
2.50	0.318
2.00	0.292
1.50	0.180
1.25	0.124
1.00	0.128
0.90	0.116
0.80	0.100
0.70	0.074
0.60	0.070
0.50	0.054

3.2 Control Point Elevation

One earthquake time history was developed for use as the input motion in performing the seismic analysis of structures. This time history represents the site specific (bedrock) earthquake motion and was used as the input for the seismic analysis of structures. The mathematical model for each seismically analyzed structure included the soil-structure interaction effects. The SSE control point elevation is defined at the top of bedrock for the Reactor Building at an elevation of 707 feet (about 50 feet below the grade).

3.3 IPEEE Description and Capacity Response Spectrum

As a reduced scope plant, the IPEEE assessment is not used for the screening evaluation.

4.0 Screening Evaluation

In accordance with SPID Section 3, a screening evaluation was performed as described below.

4.1 Risk Evaluation Screening (1 to 10 Hz)

In the 1 to 10 Hz part of the response spectrum, the SSE exceeds the GMRS. Therefore, a risk evaluation will not be performed.

4.2 High Frequency Screening (> 10 Hz)

For a portion of the range above 10 Hz, the GMRS exceeds the SSE. Therefore, the plant screens in for a high frequency confirmation.

4.3 Spent Fuel Pool Evaluation Screening (1 to 10 Hz)

In the 1 to 10 Hz part of the response spectrum, the SSE exceeds the GMRS. Therefore, a spent fuel pool evaluation will not be performed.

5.0 Interim Actions

Consistent with NRC letter dated February 20, 2014, [ML14030A046] the seismic hazard reevaluations presented herein are distinct from the current design and licensing bases of Duane Arnold Energy Center. Therefore, the results do not call into question the operability or functionality of SSCs and are not reportable pursuant to10 CFR 50.72, "Immediate notification requirements for operating nuclear power reactors," and10 CFR 50.73, "Licensee event report system."

The NRC letter also requests that licensees provide an interim evaluation or actions to demonstrate that the plant can cope with the reevaluated hazard while the expedited approach and risk evaluations are conducted. In response to that request, NEI letter dated March 12, 2014, provides seismic core damage risk estimates using the updated seismic hazards for the operating nuclear plants in the Central and Eastern United States. These risk estimates continue to support the following conclusions of the NRC GI-199 Safety/Risk Assessment:

> Overall seismic core damage risk estimates are consistent with the Commission's Safety Goal Policy Statement because they are within the subsidiary objective of 10^{-4}/year for core damage frequency. The GI-199 Safety/Risk Assessment, based in part on information from the U.S. Nuclear Regulatory Commission's (NRC's) Individual Plant Examination of External Events (IPEEE) program, indicates that no concern exists regarding adequate protection and that the current seismic design of operating reactors provides a safety margin to withstand potential earthquakes exceeding the original design basis.

Duane Arnold Energy Center is included in the March 12, 2014 risk estimates. Using the methodology described in the NEI letter, Duane Arnold Energy Center was shown to be below 10^{-4}/year; thus, the above conclusions apply.

6.0 Conclusions

In accordance with the 50.54(f) request for information, a seismic hazard and screening evaluation was performed for Duane Arnold Energy Center. A GMRS was developed solely for the purpose of screening for additional evaluations in accordance with the SPID.

Based on the results of the screening evaluation, the Duane Arnold Energy Center screens in for a High Frequency Confirmation.

7.0 References

1. Duane Arnold Energy Center (DAEC) Updated Final Safety Analysis Report, Sections 2.5 and 3.7.

2. EPRI Letter, Duane Arnold Seismic Hazard and Screening Report, dated December 23, 2013.

Appendix A

Table A-1a. Mean and Fractile Seismic Hazard Curves for PGA at Duane Arnold

AMPS(g)	MEAN	0.05	0.16	0.50	0.84	0.95
0.0005	4.37E-02	1.46E-02	2.88E-02	4.31E-02	6.00E-02	6.93E-02
0.001	2.69E-02	8.35E-03	1.62E-02	2.53E-02	3.84E-02	4.83E-02
0.005	5.40E-03	1.18E-03	2.49E-03	4.63E-03	7.89E-03	1.29E-02
0.01	2.17E-03	3.57E-04	7.23E-04	1.60E-03	3.33E-03	6.45E-03
0.015	1.12E-03	1.55E-04	3.01E-04	7.13E-04	1.67E-03	3.90E-03
0.03	3.04E-04	2.92E-05	5.58E-05	1.53E-04	4.31E-04	1.18E-03
0.05	1.12E-04	7.89E-06	1.57E-05	5.20E-05	1.69E-04	4.25E-04
0.075	5.23E-05	3.01E-06	6.64E-06	2.42E-05	8.35E-05	1.95E-04
0.1	3.13E-05	1.67E-06	3.84E-06	1.46E-05	5.12E-05	1.13E-04
0.15	1.54E-05	7.66E-07	1.84E-06	7.13E-06	2.57E-05	5.42E-05
0.3	4.29E-06	1.82E-07	4.90E-07	1.98E-06	7.45E-06	1.51E-05
0.5	1.51E-06	4.90E-08	1.53E-07	6.64E-07	2.60E-06	5.50E-06
0.75	5.98E-07	1.40E-08	4.98E-08	2.46E-07	1.04E-06	2.29E-06
1.	2.92E-07	4.90E-09	1.98E-08	1.10E-07	5.05E-07	1.16E-06
1.5	9.70E-08	9.79E-10	4.43E-09	3.05E-08	1.62E-07	4.07E-07
3.	1.08E-08	1.27E-10	2.72E-10	2.10E-09	1.55E-08	4.77E-08
5.	1.58E-09	1.11E-10	1.21E-10	2.72E-10	1.95E-09	7.03E-09
7.5	2.79E-10	1.01E-10	1.11E-10	1.23E-10	3.68E-10	1.31E-09
10.	7.22E-11	1.01E-10	1.11E-10	1.21E-10	1.60E-10	4.07E-10

Table A-1b. Mean and Fractile Seismic Hazard Curves for 25 Hz at Duane Arnold

AMPS(g)	MEAN	0.05	0.16	0.50	0.84	0.95
0.0005	5.06E-02	2.19E-02	3.63E-02	5.05E-02	6.54E-02	7.55E-02
0.001	3.41E-02	1.31E-02	2.25E-02	3.28E-02	4.56E-02	5.83E-02
0.005	8.48E-03	2.42E-03	4.25E-03	7.45E-03	1.20E-02	1.95E-02
0.01	4.04E-03	8.85E-04	1.62E-03	3.28E-03	6.17E-03	1.05E-02
0.015	2.43E-03	4.50E-04	8.23E-04	1.79E-03	3.84E-03	7.03E-03
0.03	8.58E-04	1.20E-04	2.16E-04	5.20E-04	1.32E-03	3.01E-03
0.05	3.56E-04	3.63E-05	7.03E-05	1.92E-04	5.35E-04	1.29E-03
0.075	1.69E-04	1.36E-05	2.80E-05	8.60E-05	2.64E-04	5.91E-04
0.1	9.87E-05	6.93E-06	1.51E-05	4.98E-05	1.60E-04	3.47E-04
0.15	4.71E-05	2.88E-06	6.64E-06	2.39E-05	8.00E-05	1.67E-04
0.3	1.41E-05	7.66E-07	1.84E-06	7.23E-06	2.53E-05	4.90E-05
0.5	5.73E-06	2.76E-07	7.23E-07	2.88E-06	1.05E-05	2.04E-05
0.75	2.68E-06	1.11E-07	3.19E-07	1.32E-06	4.98E-06	9.79E-06
1.	1.51E-06	5.50E-08	1.67E-07	7.23E-07	2.76E-06	5.66E-06
1.5	6.25E-07	1.77E-08	5.91E-08	2.80E-07	1.15E-06	2.42E-06
3.	1.10E-07	1.77E-09	6.93E-09	4.01E-08	1.90E-07	4.63E-07
5.	2.43E-08	2.96E-10	1.02E-09	7.03E-09	3.90E-08	1.07E-07
7.5	6.25E-09	1.32E-10	2.49E-10	1.44E-09	9.51E-09	2.84E-08
10.	2.18E-09	1.21E-10	1.38E-10	4.70E-10	3.14E-09	9.93E-09

Table A-1c. Mean and Fractile Seismic Hazard Curves for 10 Hz at Duane Arnold

AMPS(g)	MEAN	0.05	0.16	0.50	0.84	0.95
0.0005	6.06E-02	3.79E-02	4.56E-02	6.09E-02	7.45E-02	8.35E-02
0.001	4.49E-02	2.39E-02	3.14E-02	4.43E-02	5.83E-02	6.73E-02
0.005	1.20E-02	4.70E-03	6.93E-03	1.11E-02	1.67E-02	2.29E-02
0.01	5.60E-03	1.72E-03	2.76E-03	4.98E-03	8.23E-03	1.18E-02
0.015	3.37E-03	8.47E-04	1.42E-03	2.84E-03	5.20E-03	7.89E-03
0.03	1.19E-03	2.19E-04	3.84E-04	8.47E-04	1.90E-03	3.42E-03
0.05	4.79E-04	7.34E-05	1.29E-04	3.05E-04	7.23E-04	1.53E-03
0.075	2.17E-04	2.84E-05	5.12E-05	1.29E-04	3.33E-04	7.03E-04
0.1	1.21E-04	1.42E-05	2.60E-05	6.93E-05	1.95E-04	3.90E-04
0.15	5.32E-05	5.27E-06	1.01E-05	3.01E-05	9.24E-05	1.72E-04
0.3	1.38E-05	1.04E-06	2.25E-06	7.89E-06	2.53E-05	4.50E-05
0.5	5.15E-06	3.28E-07	8.00E-07	2.88E-06	9.51E-06	1.69E-05
0.75	2.25E-06	1.29E-07	3.28E-07	1.23E-06	4.25E-06	7.55E-06
1.	1.20E-06	6.09E-08	1.67E-07	6.45E-07	2.25E-06	4.07E-06
1.5	4.59E-07	1.92E-08	5.75E-08	2.35E-07	8.60E-07	1.62E-06
3.	6.84E-08	1.82E-09	6.36E-09	2.96E-08	1.21E-07	2.64E-07
5.	1.32E-08	2.96E-10	8.98E-10	4.70E-09	2.22E-08	5.42E-08
7.5	3.03E-09	1.31E-10	2.19E-10	9.37E-10	4.83E-09	1.32E-08
10.	9.71E-10	1.16E-10	1.32E-10	3.19E-10	1.53E-09	4.43E-09

Table A-1d. Mean and Fractile Seismic Hazard Curves for 5 Hz at Duane Arnold

AMPS(g)	MEAN	0.05	0.16	0.50	0.84	0.95
0.0005	6.33E-02	4.01E-02	4.77E-02	6.36E-02	7.77E-02	8.72E-02
0.001	4.88E-02	2.60E-02	3.33E-02	4.77E-02	6.45E-02	7.34E-02
0.005	1.32E-02	5.05E-03	7.45E-03	1.23E-02	1.90E-02	2.35E-02
0.01	5.83E-03	1.82E-03	2.96E-03	5.42E-03	8.72E-03	1.13E-02
0.015	3.35E-03	8.60E-04	1.49E-03	2.96E-03	5.20E-03	7.13E-03
0.03	1.04E-03	1.90E-04	3.52E-04	7.89E-04	1.64E-03	2.80E-03
0.05	3.65E-04	5.42E-05	1.02E-04	2.39E-04	5.50E-04	1.11E-03
0.075	1.47E-04	1.87E-05	3.57E-05	8.72E-05	2.22E-04	4.50E-04
0.1	7.54E-05	8.72E-06	1.67E-05	4.37E-05	1.20E-04	2.35E-04
0.15	2.97E-05	2.96E-06	5.75E-06	1.72E-05	5.12E-05	9.51E-05
0.3	6.61E-06	4.90E-07	1.10E-06	3.84E-06	1.23E-05	2.13E-05
0.5	2.23E-06	1.34E-07	3.37E-07	1.23E-06	4.19E-06	7.45E-06
0.75	8.94E-07	4.50E-08	1.23E-07	4.77E-07	1.67E-06	3.09E-06
1.	4.47E-07	1.90E-08	5.66E-08	2.29E-07	8.23E-07	1.60E-06
1.5	1.55E-07	5.05E-09	1.64E-08	7.23E-08	2.84E-07	5.83E-07
3.	1.97E-08	4.19E-10	1.40E-09	7.34E-09	3.37E-08	8.00E-08
5.	3.39E-09	1.32E-10	2.29E-10	1.01E-09	5.27E-09	1.44E-08
7.5	7.11E-10	1.11E-10	1.21E-10	2.39E-10	1.07E-09	3.19E-09
10.	2.14E-10	1.07E-10	1.21E-10	1.34E-10	3.57E-10	1.02E-09

Table A-1e. Mean and Fractile Seismic Hazard Curves for 2.5 Hz at Duane Arnold

AMPS(g)	MEAN	0.05	0.16	0.50	0.84	0.95
0.0005	5.74E-02	3.42E-02	4.19E-02	5.66E-02	7.34E-02	8.23E-02
0.001	4.11E-02	2.07E-02	2.68E-02	3.95E-02	5.66E-02	6.54E-02
0.005	9.50E-03	3.63E-03	5.35E-03	8.85E-03	1.38E-02	1.74E-02
0.01	4.06E-03	1.20E-03	1.95E-03	3.68E-03	6.17E-03	8.12E-03
0.015	2.26E-03	5.12E-04	8.85E-04	1.92E-03	3.63E-03	5.20E-03
0.03	6.06E-04	8.60E-05	1.62E-04	4.13E-04	1.01E-03	1.82E-03
0.05	1.69E-04	1.84E-05	3.68E-05	1.02E-04	2.60E-04	5.83E-04
0.075	5.28E-05	4.98E-06	1.05E-05	3.01E-05	8.23E-05	1.87E-04
0.1	2.26E-05	1.95E-06	4.25E-06	1.27E-05	3.73E-05	7.89E-05
0.15	7.28E-06	5.42E-07	1.21E-06	4.07E-06	1.29E-05	2.49E-05
0.3	1.34E-06	6.26E-08	1.64E-07	6.73E-07	2.39E-06	4.83E-06
0.5	4.05E-07	1.23E-08	3.84E-08	1.77E-07	7.13E-07	1.55E-06
0.75	1.49E-07	2.96E-09	1.08E-08	5.75E-08	2.60E-07	6.00E-07
1.	7.05E-08	1.04E-09	4.01E-09	2.42E-08	1.20E-07	2.92E-07
1.5	2.26E-08	2.64E-10	8.98E-10	6.36E-09	3.63E-08	9.79E-08
3.	2.50E-09	1.21E-10	1.38E-10	4.90E-10	3.42E-09	1.13E-08
5.	3.83E-10	1.08E-10	1.21E-10	1.38E-10	5.05E-10	1.77E-09
7.5	7.32E-11	1.01E-10	1.11E-10	1.21E-10	1.64E-10	4.01E-10
10.	2.06E-11	1.01E-10	1.11E-10	1.21E-10	1.21E-10	1.79E-10

Table A-1f. Mean and Fractile Seismic Hazard Curves for 1 Hz at Duane Arnold

AMPS(g)	MEAN	0.05	0.16	0.50	0.84	0.95
0.0005	3.66E-02	1.51E-02	2.25E-02	3.57E-02	5.05E-02	6.00E-02
0.001	2.23E-02	8.23E-03	1.29E-02	2.10E-02	3.14E-02	3.95E-02
0.005	4.93E-03	1.38E-03	2.39E-03	4.56E-03	7.55E-03	9.79E-03
0.01	2.32E-03	3.68E-04	7.55E-04	1.95E-03	3.90E-03	5.58E-03
0.015	1.35E-03	1.38E-04	3.14E-04	9.93E-04	2.42E-03	3.79E-03
0.03	3.81E-04	1.87E-05	4.90E-05	1.92E-04	7.03E-04	1.36E-03
0.05	1.04E-04	3.42E-06	9.37E-06	4.07E-05	1.74E-04	4.13E-04
0.075	2.98E-05	8.00E-07	2.25E-06	1.02E-05	4.50E-05	1.25E-04
0.1	1.11E-05	2.76E-07	7.77E-07	3.73E-06	1.60E-05	4.70E-05
0.15	2.53E-06	5.75E-08	1.67E-07	8.60E-07	3.57E-06	1.08E-05
0.3	2.44E-07	3.33E-09	1.23E-08	7.13E-08	3.90E-07	1.05E-06
0.5	6.00E-08	4.13E-10	1.64E-09	1.32E-08	8.47E-08	2.64E-07
0.75	2.09E-08	1.44E-10	3.73E-10	3.28E-09	2.68E-08	9.24E-08
1.	9.62E-09	1.21E-10	1.79E-10	1.20E-09	1.13E-08	4.25E-08
1.5	3.02E-09	1.16E-10	1.21E-10	3.19E-10	3.01E-09	1.32E-08
3.	3.32E-10	1.01E-10	1.11E-10	1.21E-10	3.05E-10	1.34E-09
5.	5.22E-11	1.01E-10	1.11E-10	1.21E-10	1.25E-10	2.60E-10
7.5	1.04E-11	1.01E-10	1.11E-10	1.21E-10	1.21E-10	1.31E-10
10.	3.02E-12	1.01E-10	1.11E-10	1.21E-10	1.21E-10	1.21E-10

Table A-1g. Mean and Fractile Seismic Hazard Curves for 0.5 Hz at Duane Arnold

AMPS(g)	MEAN	0.05	0.16	0.50	0.84	0.95
0.0005	1.82E-02	7.89E-03	1.16E-02	1.74E-02	2.46E-02	3.05E-02
0.001	1.05E-02	4.25E-03	6.36E-03	9.93E-03	1.46E-02	1.92E-02
0.005	2.71E-03	4.43E-04	9.11E-04	2.35E-03	4.50E-03	6.26E-03
0.01	1.31E-03	8.72E-05	2.32E-04	9.11E-04	2.46E-03	3.84E-03
0.015	7.46E-04	2.72E-05	8.35E-05	4.01E-04	1.44E-03	2.60E-03
0.03	1.99E-04	2.72E-06	1.01E-05	6.36E-05	3.63E-04	8.60E-04
0.05	5.32E-05	4.13E-07	1.60E-06	1.18E-05	8.00E-05	2.46E-04
0.075	1.51E-05	8.47E-08	3.33E-07	2.68E-06	1.92E-05	7.03E-05
0.1	5.57E-06	2.64E-08	1.04E-07	8.60E-07	6.54E-06	2.57E-05
0.15	1.21E-06	4.63E-09	1.90E-08	1.69E-07	1.31E-06	5.35E-06
0.3	8.58E-08	2.46E-10	1.01E-09	9.79E-09	9.37E-08	3.84E-07
0.5	1.69E-08	1.21E-10	1.79E-10	1.27E-09	1.46E-08	7.23E-08
0.75	5.54E-09	1.15E-10	1.21E-10	3.09E-10	3.52E-09	2.19E-08
1.	2.56E-09	1.11E-10	1.21E-10	1.60E-10	1.34E-09	9.24E-09
1.5	8.30E-10	1.01E-10	1.11E-10	1.21E-10	3.63E-10	2.68E-09
3.	9.89E-11	1.01E-10	1.11E-10	1.21E-10	1.21E-10	3.09E-10
5.	1.67E-11	1.01E-10	1.11E-10	1.21E-10	1.21E-10	1.29E-10
7.5	3.54E-12	1.01E-10	1.11E-10	1.21E-10	1.21E-10	1.21E-10
10.	1.08E-12	1.01E-10	1.11E-10	1.21E-10	1.21E-10	1.21E-10

Table A-2a. Amplification Functions for Duane Arnold

PGA	Median AF	Sigma ln(AF)	25 Hz	Median AF	Sigma ln(AF)	10 Hz	Median AF	Sigma ln(AF)	5 Hz	Median AF	Sigma ln(AF)
1.00E-02	9.83E-01	3.41E-02	1.30E-02	9.12E-01	4.36E-02	1.90E-02	9.67E-01	7.36E-02	2.09E-02	1.05E+00	6.57E-02
4.95E-02	8.98E-01	4.49E-02	1.02E-01	7.98E-01	8.38E-02	9.99E-02	9.55E-01	8.55E-02	8.24E-02	1.05E+00	6.77E-02
9.64E-02	8.67E-01	4.83E-02	2.13E-01	7.80E-01	9.13E-02	1.85E-01	9.51E-01	8.69E-02	1.44E-01	1.05E+00	6.77E-02
1.94E-01	8.44E-01	5.06E-02	4.43E-01	7.68E-01	9.44E-02	3.56E-01	9.46E-01	8.73E-02	2.65E-01	1.05E+00	6.76E-02
2.92E-01	8.31E-01	5.17E-02	6.76E-01	7.61E-01	9.56E-02	5.23E-01	9.41E-01	8.75E-02	3.84E-01	1.05E+00	6.77E-02
3.91E-01	8.23E-01	5.23E-02	9.09E-01	7.56E-01	9.63E-02	6.90E-01	9.38E-01	8.77E-02	5.02E-01	1.04E+00	6.80E-02
4.93E-01	8.17E-01	5.28E-02	1.15E+00	7.52E-01	9.67E-02	8.61E-01	9.35E-01	8.79E-02	6.22E-01	1.04E+00	6.82E-02
7.41E-01	8.06E-01	5.35E-02	1.73E+00	7.43E-01	9.72E-02	1.27E+00	9.28E-01	8.86E-02	9.13E-01	1.04E+00	6.89E-02
1.01E+00	7.98E-01	5.41E-02	2.36E+00	7.35E-01	9.79E-02	1.72E+00	9.22E-01	8.97E-02	1.22E+00	1.04E+00	6.97E-02
1.28E+00	7.92E-01	5.46E-02	3.01E+00	7.29E-01	9.87E-02	2.17E+00	9.16E-01	9.07E-02	1.54E+00	1.04E+00	7.06E-02
1.55E+00	7.87E-01	5.46E-02	3.63E+00	7.23E-01	9.92E-02	2.61E+00	9.12E-01	9.15E-02	1.85E+00	1.04E+00	7.13E-02
2.5 Hz	**Median AF**	**Sigma ln(AF)**	**1 Hz**	**Median AF**	**Sigma ln(AF)**	**0.5 Hz**	**Median AF**	**Sigma ln(AF)**			
2.18E-02	9.75E-01	6.23E-02	1.27E-02	1.10E+00	9.36E-02	8.25E-03	1.14E+00	1.01E-01			
7.05E-02	9.72E-01	6.17E-02	3.43E-02	1.10E+00	9.12E-02	1.96E-02	1.13E+00	9.70E-02			
1.18E-01	9.71E-01	6.13E-02	5.51E-02	1.10E+00	9.04E-02	3.02E-02	1.13E+00	9.58E-02			
2.12E-01	9.71E-01	6.11E-02	9.63E-02	1.10E+00	8.97E-02	5.11E-02	1.13E+00	9.50E-02			
3.04E-01	9.71E-01	6.10E-02	1.36E-01	1.10E+00	8.93E-02	7.10E-02	1.13E+00	9.47E-02			
3.94E-01	9.71E-01	6.09E-02	1.75E-01	1.10E+00	8.91E-02	9.06E-02	1.13E+00	9.46E-02			
4.86E-01	9.71E-01	6.10E-02	2.14E-01	1.10E+00	8.90E-02	1.10E-01	1.13E+00	9.46E-02			
7.09E-01	9.72E-01	6.11E-02	3.10E-01	1.10E+00	8.88E-02	1.58E-01	1.13E+00	9.46E-02			
9.47E-01	9.74E-01	6.15E-02	4.12E-01	1.10E+00	8.88E-02	2.09E-01	1.13E+00	9.47E-02			
1.19E+00	9.75E-01	6.18E-02	5.18E-01	1.10E+00	8.87E-02	2.62E-01	1.13E+00	9.48E-02			
1.43E+00	9.76E-01	6.20E-02	6.19E-01	1.10E+00	8.88E-02	3.12E-01	1.13E+00	9.49E-02			

Tables A2-b1 and A2-b2 are tabular versions of the typical amplification factors provided in Figures 2.3.6-1 and 2.3.6-2. Values are provided for two input motion levels at approximately 10^{-4} and 10^{-5} mean annual frequency of exceedance. These factors are unverified and are provided for information only. The figures should be considered the governing information.

Table A2-b1. Median AFs and sigmas for Model 1, Profile 1, for 2 PGA levels.

M1P1K1	Rock PGA=0.0495			M1P1K1	PGA=0.194		
Freq. (Hz)	Soil_SA	med. AF	sigma ln(AF)	Freq. (Hz)	Soil_SA	med. AF	sigma ln(AF)
100.0	0.045	0.908	0.040	100.0	0.166	0.855	0.053
87.1	0.045	0.904	0.040	87.1	0.168	0.847	0.055
75.9	0.046	0.896	0.042	75.9	0.173	0.832	0.057
66.1	0.047	0.880	0.044	66.1	0.182	0.803	0.063
57.5	0.050	0.852	0.051	57.5	0.202	0.760	0.079
50.1	0.055	0.825	0.063	50.1	0.236	0.741	0.099
43.7	0.062	0.801	0.084	43.7	0.274	0.728	0.123
38.0	0.068	0.786	0.108	38.0	0.303	0.730	0.145
33.1	0.074	0.781	0.113	33.1	0.323	0.737	0.142
28.8	0.080	0.818	0.108	28.8	0.344	0.783	0.128
25.1	0.085	0.835	0.108	25.1	0.357	0.805	0.122
21.9	0.088	0.878	0.097	21.9	0.361	0.855	0.107
19.1	0.092	0.892	0.094	19.1	0.364	0.873	0.099
16.6	0.097	0.949	0.093	16.6	0.375	0.935	0.100
14.5	0.098	0.971	0.108	14.5	0.368	0.960	0.111
12.6	0.099	0.982	0.112	12.6	0.362	0.971	0.116
11.0	0.098	0.973	0.093	11.0	0.351	0.963	0.096
9.5	0.097	0.985	0.070	9.5	0.339	0.975	0.073
8.3	0.095	1.023	0.072	8.3	0.326	1.015	0.073
7.2	0.094	1.059	0.057	7.2	0.317	1.053	0.057
6.3	0.093	1.086	0.073	6.3	0.306	1.081	0.072
5.5	0.090	1.087	0.073	5.5	0.293	1.084	0.073
4.8	0.087	1.053	0.075	4.8	0.278	1.051	0.075
4.2	0.082	1.010	0.085	4.2	0.258	1.008	0.084
3.6	0.077	0.956	0.065	3.6	0.238	0.955	0.064
3.2	0.072	0.945	0.054	3.2	0.222	0.945	0.053
2.8	0.067	0.916	0.071	2.8	0.204	0.916	0.070
2.4	0.063	0.914	0.060	2.4	0.188	0.914	0.060
2.1	0.059	0.928	0.052	2.1	0.174	0.927	0.052
1.8	0.054	0.942	0.076	1.8	0.158	0.941	0.075
1.6	0.048	0.954	0.057	1.6	0.138	0.953	0.057
1.4	0.045	1.042	0.075	1.4	0.130	1.039	0.074
1.2	0.044	1.133	0.059	1.2	0.124	1.129	0.058
1.0	0.039	1.120	0.064	1.0	0.111	1.116	0.063
0.91	0.034	1.039	0.062	0.91	0.094	1.038	0.061
0.79	0.029	0.984	0.055	0.79	0.081	0.984	0.054
0.69	0.026	0.981	0.059	0.69	0.071	0.980	0.058
0.60	0.024	1.016	0.056	0.60	0.064	1.015	0.055
0.52	0.022	1.070	0.043	0.52	0.058	1.067	0.043
0.46	0.020	1.121	0.034	0.46	0.050	1.116	0.033
0.10	0.001	1.049	0.018	0.10	0.002	1.045	0.018

Table A2-b2. Median AFs and sigmas for Model 2, Profile 1, for 2 PGA levels.

M2P1K1	PGA=0.0495			M2P1K1	PGA=0.194		
Freq. (Hz)	Soil_SA	med. AF	sigma ln(AF)	Freq. (Hz)	Soil_SA	med. AF	sigma ln(AF)
100.0	0.045	0.905	0.037	100.0	0.167	0.862	0.048
87.1	0.045	0.901	0.037	87.1	0.170	0.854	0.049
75.9	0.046	0.893	0.038	75.9	0.175	0.839	0.050
66.1	0.047	0.877	0.039	66.1	0.184	0.811	0.054
57.5	0.050	0.848	0.044	57.5	0.204	0.768	0.068
50.1	0.055	0.820	0.053	50.1	0.240	0.752	0.084
43.7	0.061	0.795	0.070	43.7	0.278	0.739	0.105
38.0	0.067	0.780	0.096	38.0	0.307	0.740	0.132
33.1	0.073	0.776	0.102	33.1	0.328	0.748	0.129
28.8	0.079	0.813	0.101	28.8	0.349	0.794	0.118
25.1	0.084	0.831	0.105	25.1	0.362	0.816	0.119
21.9	0.088	0.874	0.092	21.9	0.365	0.864	0.102
19.1	0.091	0.888	0.093	19.1	0.368	0.882	0.100
16.6	0.097	0.945	0.095	16.6	0.378	0.944	0.101
14.5	0.098	0.968	0.111	14.5	0.371	0.969	0.115
12.6	0.099	0.979	0.112	12.6	0.365	0.979	0.117
11.0	0.098	0.971	0.094	11.0	0.353	0.970	0.097
9.5	0.097	0.984	0.072	9.5	0.342	0.982	0.074
8.3	0.095	1.022	0.072	8.3	0.328	1.021	0.073
7.2	0.094	1.058	0.058	7.2	0.318	1.058	0.059
6.3	0.092	1.084	0.068	6.3	0.306	1.084	0.068
5.5	0.090	1.086	0.069	5.5	0.293	1.086	0.069
4.8	0.087	1.052	0.072	4.8	0.278	1.052	0.072
4.2	0.082	1.009	0.084	4.2	0.259	1.009	0.084
3.6	0.077	0.956	0.066	3.6	0.238	0.955	0.066
3.2	0.072	0.945	0.054	3.2	0.222	0.945	0.053
2.8	0.067	0.916	0.071	2.8	0.204	0.916	0.070
2.4	0.063	0.914	0.060	2.4	0.188	0.914	0.060
2.1	0.059	0.928	0.052	2.1	0.174	0.927	0.052
1.8	0.054	0.942	0.076	1.8	0.158	0.941	0.075
1.6	0.048	0.954	0.057	1.6	0.138	0.953	0.056
1.4	0.045	1.042	0.075	1.4	0.130	1.039	0.074
1.2	0.044	1.133	0.059	1.2	0.124	1.129	0.058
1.0	0.039	1.120	0.064	1.0	0.111	1.116	0.063
0.91	0.034	1.039	0.062	0.91	0.094	1.038	0.061
0.79	0.029	0.984	0.055	0.79	0.081	0.984	0.054
0.69	0.026	0.981	0.059	0.69	0.071	0.980	0.058
0.60	0.024	1.016	0.056	0.60	0.064	1.015	0.055
0.52	0.022	1.070	0.043	0.52	0.058	1.067	0.042
0.46	0.020	1.121	0.034	0.46	0.050	1.116	0.033
0.10	0.001	1.049	0.018	0.10	0.002	1.045	0.018