Exelon Generation®

RS-14-072

10 CFR 50.54(f)

March 31, 2014

U.S. Nuclear Regulatory Commission
Attn: Document Control Desk
11555 Rockville Pike,
Rockville, MD 20852

Quad Cities Nuclear Power Station, Units 1 and 2
Renewed Facility Operating License Nos. DPR-29 and DPR-30
NRC Docket Nos. 50-254 and 50-265

Subject: Exelon Generation Company, LLC, Seismic Hazard and Screening Report (Central and Eastern United States (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
2. NEI Letter, Proposed Path Forward for NTTF Recommendation 2.1: Seismic Reevaluations, dated April 9, 2013
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
4. Exelon Generation Company, LLC letter to the NRC, Response to NRC Request for Information Pursuant to 10 CFR 50.54(f) Regarding the Seismic Aspects of Recommendation 2.1 of the Near-Term Task Force Review of Insights from the Fukushima Dai-ichi Accident – 1.5 Year Response for CEUS Sites, dated September 12, 2013
5. 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
6. NRC Letter, Endorsement of Electric Power Research Institute Final Draft Report 1025287, "Seismic Evaluation Guidance," dated February 15, 2013
7. EPRI Technical Report 3002000704, "Seismic Evaluation Guidance: Augmented Approach for the Resolution of Fukushima Near-Term Task Force Recommendation 2.1: Seismic," dated May 2013

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 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. In Reference 4, Exelon Generation Company, LLC (EGC) provided the description of subsurface materials and properties and base case velocity profiles for Quad Cities Nuclear Power Station, Units 1 and 2.

Reference 5 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 6.

The enclosed Seismic Hazard Evaluation and Screening Report for Quad Cities Nuclear Power Station, Units 1 and 2, provides the information described in Section 4 of Reference 5 in accordance with the schedule identified in Reference 2. As described in Enclosure 1, Quad Cities Nuclear Power Station, Units 1 and 2, meet the requirements of SPID Sections 3.2 and 7 (Reference 5) and therefore screen out and do not need to prepare an Expedited Seismic Evaluation Process (ESEP) Report in accordance with Reference 7. Quad Cities Nuclear Power Station, Units 1 and 2, do not need to perform a High Frequency Confirmation evaluation. Additionally, no Seismic Risk Assessment or Spent Fuel Pool evaluation, or any interim actions are needed.

This letter contains no new regulatory commitments. If you have any questions regarding this report, please contact Ron Gaston at (630) 657-3359.

I declare under penalty of perjury that the foregoing is true and correct. Executed on the 31st day of March 2014.

Respectfully submitted,

Glen T. Kaegi

Glen T. Kaegi
Director - Licensing & Regulatory Affairs
Exelon Generation Company, LLC

Enclosure:

1. Quad Cities Nuclear Power Station, Units 1 and 2, Seismic Hazard and Screening Report

cc: Director, Office of Nuclear Reactor Regulation
Regional Administrator - NRC Region III
NRC Senior Resident Inspector – Quad Cities Nuclear Power Station
NRC Project Manager, NRR – Quad Cities Nuclear Power Station
Ms. Jessica A. Kratchman, NRR/JLD/PMB, NRC
Mr. Eric E. Bowman, NRR/DPR/PGCB, NRC or Ms. Eileen M. McKenna, NRO/DSRA/BPTS, NRC
Illinois Emergency Management Agency - Division of Nuclear Safety

# Enclosure 1

## Quad Cities Nuclear Power Station, Units 1 and 2

## Seismic Hazard and Screening Report

(52 pages)

# SEISMIC HAZARD AND SCREENING REPORT
## IN RESPONSE TO THE 50.54(f) INFORMATION REQUEST REGARDING FUKUSHIMA NEAR-TERM TASK FORCE RECOMMENDATION 2.1: SEISMIC

## for the

## *Quad Cities Generating Station, Units 1 and 2*
## *22710 206th Avenue North, Cordova, Illinois 61242-9740*
## Facility Operating License Nos. DPR-29 and DPR-30
## NRC Docket Nos. STN 50-254 and STN 50-265
## Correspondence No.: RS-14-072

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Exelon

Exelon Generation Company, LLC (Exelon)
PO Box 805398
Chicago, IL 60680-5398

Prepared by:
Sargent & Lundy LLC
55 East Monroe Street, Chicago, IL 60603

Report Number: SL-012196, Revision 0

| | Printed Name | Signature | Date |
|---|---|---|---|
| Preparer: | Ryan Foley | for R.F. | 3-14-14 |
| Reviewer: | Ronald Boehm | | 3-14-2014 |
| Approver: | Javad Moslemian | | 3/14/14 |
| Lead Responsible Engineer: | JULIE KIM | | 3/18/14 |
| Branch Manager: | Douglas F Collins | | 03/18/14 |
| Senior Manager<br>Design Engineering: | C. ALGUIRE | C. Alguire | 3-18-14 |
| Corporate Acceptance: | Jeffrey S. Clark | Jeffrey S. Clark | 3/18/14 |

Exelon.

Sargent & Lundy LLC

# Seismic Hazard and Screening Report – Quad Cities Units 1 and 2

Report No.: SL-012196
Revision 0 – Initial Issue

S&L Project No.: 11332-186
Nuclear Non-Safety Related

**Sections: Executive Summary, 1.0, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, and Appendix A**

|  |  |  |
|---|---|---|
| Prepared by: | for R.F.<br>Ryan Foley | 3-14-14<br>Date |
| Reviewed by: | R Boehm<br>Ronald Boehm | 3-14-2014<br>Date |
| Approved by: | Javad Moslemian<br>Javad Moslemian | 3/14/14<br>Date |

# RECORD OF REVISIONS

| Revision | Affected Pages | Description |
|---|---|---|
| 0 | All | Initial Issue |

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# Executive Summary

## PURPOSE

Following the accident at the Fukushima Daiichi nuclear power plant resulting from the March 11, 2011, Great Tohoku Earthquake and subsequent tsunami, the Nuclear Regulatory Commission (NRC) issued a 50.54(f) letter (Reference 1) requesting information in response to NRC Near-Term Task Force (NTTF) recommendations intended to clarify and strengthen the regulatory framework for protection against natural phenomena. The 50.54(f) letter (Reference 1) requests that licensees and holders of construction permits under Title 10 Code of Federal Regulations Part 50 (Reference 2) reevaluate the seismic hazards at their sites against present-day NRC requirements. 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 (Reference 1) pertaining to NTTF Recommendation 2.1 for Quad Cities Generating Station Units 1 and 2 (Quad Cities station) in accordance with the documented intention of Exelon Generating Company transmitted to the NRC via letter dated April 29, 2013 (Reference 20).

## SCOPE

In response to the 50.54(f) letter (Reference 1) and following the Screening, Prioritization, and Implementation Details (SPID) industry guidance document (Reference 3), a seismic hazard reevaluation for Quad Cities station was performed to develop a Ground Motion Response Spectrum (GMRS) for comparison with the Safe Shutdown Earthquake (SSE). Consistent with NRC letter dated February 20, 2014, (Reference 25) the seismic hazard reevaluations performed in response to the 50.54(f) letter (Reference 1) are distinct from the current design or licensing bases of operating plants. Therefore, the results generally do not call into question the operability or functionality of SSCs and are not expected to be reportable pursuant to 10 CFR 50.72, "Immediate notification requirements for operating nuclear power reactors," and 10 CFR 50.73, "Licensee event report system."

Section 2 provides a summary of the Quad Cities station regional and local geology, seismicity, other major inputs to the seismic hazard reevaluation, and detailed seismic hazard results including definition of the GMRS. Seismic hazard analysis for Quad Cities station, including site response evaluation and GMRS development (Sections 2.2, 2.3, and 2.4 of this report) was performed by the Electric Power Research Institute (EPRI) (Reference 16). A more in-depth discussion of the calculation methods used in the seismic hazard reevaluation can be found in References 3, 7, 8, 14, and 17. Section 3 describes the characteristics of the appropriate plant-level SSE for Quad Cities station. Section 4 provides a comparison of the GMRS to the controlling SSE for Quad Cities station. Sections 5 and 6 discuss interim actions and conclusions, respectively, for Quad Cities station.

## CONCLUSIONS

The seismic hazard reevaluation for Quad Cities station compared the Ground Motion Response Spectrum (GMRS) with the Safe Shutdown Earthquake (SSE) spectrum. Quad Cities station is defined by multiple SSE spectra, and therefore comparisons of the GMRS were performed to the appropriate SSE spectra. It was determined that the controlling SSE exceeds the GMRS for the entire spectral frequency range of interest. Therefore, it is concluded that no further evaluations are necessary in response to the 50.54(f) letter (Reference 1).

# 1

# 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 (Reference 1). The 50.54(f) letter requests that licensees and holders of construction permits under 10 CFR Part 50 (Reference 2) 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 (Reference 1) pertaining to NTTF Recommendation 2.1 for the Quad Cities Generating Station Units 1 and 2 (Quad Cities station), located in Rock Island County, Illinois. In providing this information, Exelon 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* (Reference 3). The Augmented Approach, *Seismic Evaluation Guidance: Augmented Approach for the Resolution of Fukushima Near-Term Task Force Recommendation 2.1: Seismic* (Reference 4), has been developed as the process for evaluating critical plant equipment as an interim action to demonstrate additional plant safety margin, prior to performing the complete plant seismic risk evaluations. The SPID (Reference 3) and Augmented Approach (Reference 4) have been endorsed by the NRC in letters to NEI per Reference 23 and Reference 24 respectively.

The original geological and seismological siting investigations for the Quad Cities station satisfy the site criteria contained in Title 10 Code of Federal Regulations Part 100 (Reference 5). The Safe Shutdown Earthquake (SSE) ground motion was developed based on a review of the seismology, geology, and other site data as documented in Volume II, Appendix F, of the Quad Cities Plant Design Analysis Report (PDAR) and is used for the design of seismic Category I systems, structures and components (Reference 10). See Section 3 of this report for further discussion on the development of the Quad Cities station SSE.

In response to the 50.54(f) letter (Reference 1) and following the guidance provided in the SPID (Reference 3), a seismic hazard reevaluation for Quad Cities station was performed. For screening purposes, a Ground Motion Response Spectrum (GMRS) was developed.

# 2

# Seismic Hazard Reevaluation

Quad Cities Generating Station is located in Rock Island County on the east bank of the Mississippi River, about 3 miles north of Cordova, Illinois, 20 miles northeast of the Quad-Cities area. The Quad Cities station site is located on the extreme northwest flank of the Illinois Basin. The bedrock in the region is generally covered by unconsolidated deposits of glacial till, outwash, and lacustrine sediment. The Paleozoic sedimentary rocks underlying the region are the Niagaran and Alexandrian formations which are dolomitic rocks of Silurian age. The plant structures are founded on the top of the Niagaran dolomite. The SSE control point is defined at elevation 550 feet (see Section 3.2). Some cavities and crevices in the rock underlying the site were filled using a grouting procedure. The resulting grout-rock complex rests on sound bedrock. There is little evidence of faulting in the area, and therefore surface faulting is not an issue which required evaluations at Quad Cities station. (References 9, 10, and 18)

A seismology study was performed during the plant design phase in order to determine the appropriate seismic design criteria for Quad Cities station and is documented in Reference 18. The seismology study indicates that earthquake activity originating within several hundred miles of the Quad Cities station includes relatively frequent earthquakes of small intensity from close-by sources, with occasional stronger motion from earthquakes of somewhat higher intensity. While the vast majority of earthquakes near the Quad Cities station will result in minor ground accelerations, the risk of a Modified Mercalli VII occurring very close to the site was considered realistic, although the frequency of occurrence is low. Based on the seismology study, a recommended design ground acceleration of 0.12g was considered for the Operating Basis Earthquake (OBE) and the SSE was considered as twice the OBE, or 0.24g PGA. (Reference 18)

## 2.1 REGIONAL AND LOCAL GEOLOGY

The bedrock in the region is generally covered by unconsolidated deposits of glacial till, outwash, and lacustrine sediment ranging in thickness from 0 to 300 feet deposited as a result of different glaciations occurring during the Pleistocene Epoch. The Paleozoic sedimentary rocks underlying the region are the Niagaran and Alexandrian formations, dolomitic rocks of Silurian age. The thickness of the sedimentary rocks is on the order of 3,000 feet. The sedimentary rocks are underlain by Precambrian crystalline rocks. Bedrock valleys formed in pre-glacial times have been abandoned as stream channels and filled with unconsolidated sediments. (References 9, 10 and 18)

The site is located on moderately high ground adjacent to the Mississippi River. The site is underlain by 30 to 80 feet of glacial deposits, which consist of unconsolidated clays, silt, sand, gravel, and boulders. The glacial deposits lie on top of the weathered surface of Niagaran and Alexandrian dolomites. The Silurian dolomite is described as locally cherty and silty at the base. Ordovician and Cambrian Paleozoic rocks underlie the Silurian rocks with a basement of Precambrian igneous rock. (References 9, 10, and 18)

## 2.2 PROBABILISTIC SEISMIC HAZARD ANALYSIS

### 2.2.1 Probabilistic Seismic Hazard Analysis Results

In accordance with the 50.54(f) letter (Reference 1) and following the SPID guidance (Reference 3), a probabilistic seismic hazard analysis (PSHA) was completed using the recently developed Central and Eastern United States Seismic Source Characterization (CEUS-SSC) (Reference 7) together with the updated EPRI Ground-Motion Model (Reference 8). For the PSHA, a lower bound moment magnitude cutoff of 5.0 was used, as specified in the 50.54(f) letter.

For the PSHA, the CEUS-SSC (Reference 7) background seismic sources out to a distance of 400 miles around Quad Cities were included. This distance exceeds the 200 mile recommendation contained in Regulatory Guide 1.208 (Reference 17) 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. Paleozoic Extended Crust wide (PEZ_W)
11. Reelfoot Rift (RR)
12. Reelfoot Rift including the Rough Creek Graben (RR-RCG)
13. Study region (STUDY_R)

For sources of large magnitude earthquakes, designated Repeated Large Magnitude Earthquake (RLME) sources in CEUS-SSC (Reference 7), the following sources lie within 621 miles (1000 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. New Madrid Fault System (NMFS)
6. Wabash Valley

For each of the above background and RLME sources, the mid-continent version of the updated CEUS EPRI GMM (Reference 8) was used.

### 2.2.2 Base Rock Seismic Hazard Curves

Consistent with the SPID (Reference 3), 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 2.3.7 at the SSE control point elevation.

## 2.3 SITE RESPONSE EVALUATION

Following the guidance contained in Seismic Enclosure 1 of the 50.54(f) letter Request for Information (Reference 1) and in the SPID (Reference 3) for nuclear power plant sites that are not founded on hard rock (hard rock is defined as having a shear wave velocity of at least 9285 ft/sec), a site response analysis was performed for Quad Cities station.

### 2.3.1 Description of Subsurface Material

The basic information used to create the site geologic profile at the Quad Cities station is shown in Table 2.3.1-1. This profile was developed using information documented in Reference 13. As indicated in Table 2.3.1-1, the SSE Control Point is defined at elevation 550 feet, and the profile was modeled up to that elevation. The SSE is at the top of the Silurian Niagaran Formation consisting of firm dolomite. Hard crystalline rock (Precambrian basement) is at a depth of about 3,250 feet beneath the SSE control point.

The site is located on moderately high ground on the east bank of the Mississippi River. The ground surface rises abruptly from the river, forming steep bluffs approximately 20 to 40 feet in height. The site is situated in the Meredosia Channel, which is an ancient channel of the Mississippi River. The site is underlain by predominantly granular soil (unconsolidated sediments) consisting 30 to 80 feet of glacial material (Cenozoic deposits of unconsolidated clay, silt, sand, and gravel, and Pleistocene deposits of unconsolidated clay, silt, sand, gravel and boulders deposited as till, outwash, lake deposits and loess) overlying the weathered surface of Niagaran and Alexandrian dolomite. (References 9 and 18)

The granular soil layer is underlain by Silurian dolomites: the Niagaran and Alexandrian formations (dolomite, locally cherty, silty at base, thin bedded to massive, some coral reefs) (Reference 9). Core borings at the site revealed the presence of some cavities and crevices in the rock underlying the site. When the overburden was removed, the extent of the crevices was disclosed. Where practical, these voids were cleaned out and filled with concrete in accordance with a grouting procedure. (Reference 10)

The Silurian dolomite is underlain by Ordovician period Galena Dolomite and Platteville Formations (dolomite, cherty, sand and shale zones), Glenwood and St. Peter Sandstone (sandstone, fine to coarse grained, shale zones, dolomitic, locally cherty), and the Prairie de Chien Group (dolomite, sandy, cherty, some sandstone). (Reference 9)

Cambrian period formations of sedimentary rock feature dolomite, sandstone (fine to coarse grained, well sorted), siltstone, and shale. The Precambrian basement consists of igneous rock (undifferentiated granite and granodiorites). (Reference 9)

Table 2.3.1-1: Summary of geotechnical profile data for Quad Cities station (Reference 21)

| Elevations of Layer Boundaries At Reactor Buildings (ft, MSL) | Range in Thickness Across Site (ft) | Soil/Rock Description and Age | Density (pcf) | Shear Wave Velocity (fps) | Compressional Wave Velocity (fps) | Poisson's Ratio |
|---|---|---|---|---|---|---|
| 595[a] to 550 | 45-55 | Pleistocene glacial till, outwash and lacustrine deposits, unconsolidated fine sand to coarse gravels containing some cobbles and boulders | N/A | N/A | N/A | N/A |
| 550[b] to 530[c] | 10-20 | Silurian Niagaran Formation, dolomite exhibiting extensive voids and cavities due to solution[d] | 150-170 | 2000-7500 | 8100-14000 | 0.12-0.37 |
| 530 to 510 | 15-30 | Silurian Niagaran Formation, dolomite exhibiting relatively infrequent voids and cavities due to solution[d] | 150-170 | 5000-9000 | 9300-14000 | 0.12-0.37 |
| 510 to 470 | 5-40 | Silurian Niagaran Formation, dolomite exhibiting voids and cavities due to solution[d] | 150-170 | 2000-6200 | 8800-10700 | 0.12-0.37 |
| 470 to 300 | 170-250 | Silurian Niagaran and Alexandrian Formations, dolomite and dolomitic limestone with varying degrees of porosity | 150-170 | 5000-9000 | 9300-14000 | 0.12-0.37 |
| 300 to -2700 | 3000 | Ordovician and Cambrian sedimentary rocks, dolomite, shale, sandstone, and siltstone | N/A | N/A | N/A | N/A |
| -2700 and below | N/A | Precambrian crystalline basement, granite and granodiorite | N/A | N/A | N/A | N/A |

[a] Finish grade elevation is nominally 595 ft MSL.

[b] The IPEEE HCLPF and SSE control point elevations are at the top of bedrock, which is at El. 550 ft MSL.

[c] Bottom of the deepest foundation is at El. 539 ft MSL, within the upper Niagaran Formation, which exhibits extensive voids and cavities. This cavity-bearing portion of this upper zone was largely removed during excavation and backfilled with concrete prior to placing the structure foundations.

[d] Description of grouting program that was implemented to improve the structural properties of the upper bedrock is provided in UFSAR Appendix 2A (Reference 10).

### 2.3.2 Development of Base Case Profiles and Nonlinear Material Properties

Based on Table 2.3.1-1 and the location of the SSE at an elevation of 550 feet MSL (Reference 13), the profile consists of about 3,250 feet of firm rock overlying hard crystalline basement rock.

Shear-wave velocities for the profile were based on compressional-wave velocities and an assumed[1] Poisson ratio in the upper 250 feet. Both the shear- and compressional-wave velocities in Table 2.3.1-1 show a large amount of variability (±30-50%) across the site so a scale factor of 1.57 was assumed[1] to be appropriate. The mean base-case profile (P1) was developed using the mean (log) recommended shear-wave velocities (Table 2.3.1-1). Provided that the materials to basement depth reflect similar sedimentary rocks and age, in general the shear-wave velocity gradient for sedimentary rock of 0.5 ft/s/ft (Reference 3) was assumed[1] to be appropriate for the site for materials at depths greater than 250 feet. The shear-wave velocity of 6,708 ft/s was taken at a depth of 250 feet (Table 2.3.1-1) with the velocity gradient applied at that point, resulting in a base-case shear-wave velocity of about 8,200 ft/s at a depth of 3,250 feet. The mean or best estimate base-case profile is shown as profile P1 in Figure 2.3.2-1.

The lower and upper range base-case profiles were developed using the scale factor of 1.57. The scale factor of 1.57 reflects a $\sigma_{\mu ln}$ of about 0.35 based on the SPID (Reference 3) 10th and 90th fractiles which implies a 1.28 scale factor on $\sigma_{\mu}$. Mean and lower range base-case profiles P1 and P2 respectively, extended to hard rock conditions at a depth (below the SSE) of 3,250 feet, randomized ± 975 feet. Upper range base-case profile, P3, encountered hard rock conditions at a depth (below the SSE) of 80 feet. The depth randomization 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. The base-case profiles (P1, P2, and P3) are shown in Figure 2.3.2-1 and listed in Table 2.3.2-1.

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[1] Assumptions discussed in Section 2 are provided by EPRI engineers (Reference 16) in accordance with implementation of the SPID (Reference 3) methodology.

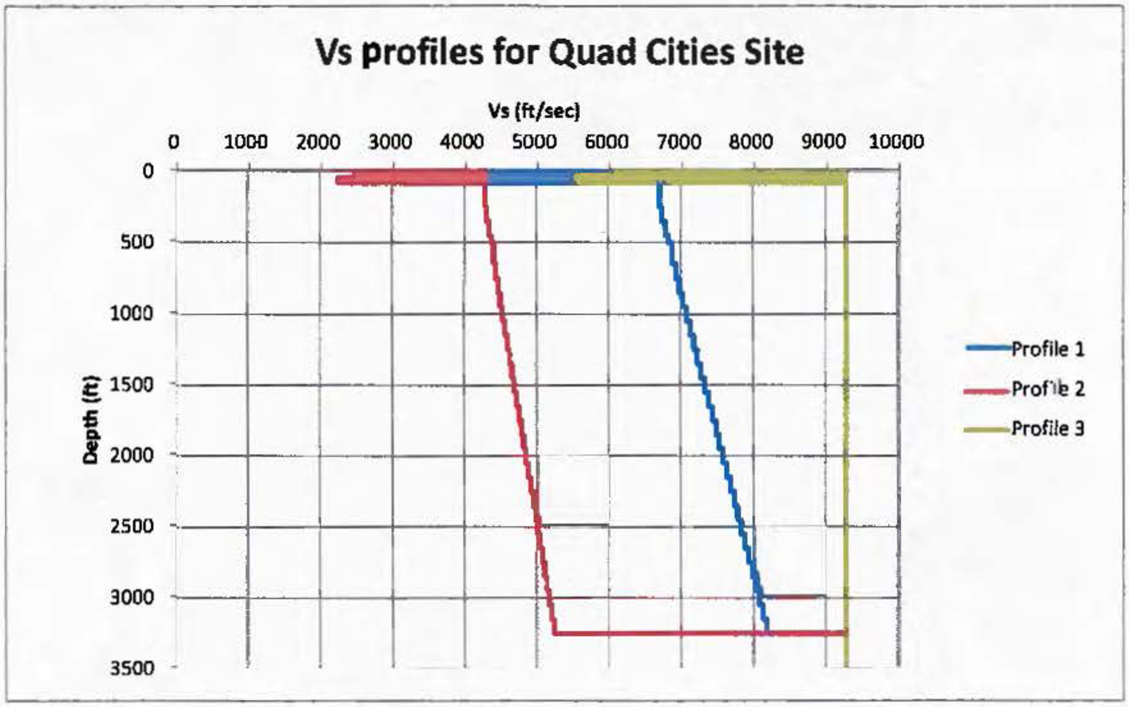

Figure 2.3.2-1: Shear-wave velocity ($V_s$) profiles for Quad Cities station (Reference 21)

Table 2.3.2-1: Layer thicknesses, depths, and shear-wave velocity ($V_s$) for three (3) profiles, Quad Cities station (Reference 21)

| Profile 1 (P1) | | | Profile 2 (P2) | | | Profile 3 (P3) | | |
|---|---|---|---|---|---|---|---|---|
| Thickness (ft) | Depth (ft) | Vs (ft/s) | Thickness (ft) | Depth (ft) | Vs (ft/s) | Thickness (ft) | Depth (ft) | Vs (ft/s) |
| | 0 | 3873 | | 0 | 2479 | | 0 | 6080 |
| 6.7 | 6.7 | 3873 | 6.7 | 6.7 | 2479 | 6.7 | 6.7 | 6080 |
| 6.7 | 13.3 | 3873 | 6.7 | 13.3 | 2479 | 6.7 | 13.3 | 6080 |
| 6.7 | 20.0 | 3873 | 6.7 | 20.0 | 2479 | 6.7 | 20.0 | 6080 |
| 5.0 | 25.0 | 6708 | 5.0 | 25.0 | 4293 | 5.0 | 25.0 | 9285 |
| 8.3 | 33.3 | 6708 | 8.3 | 33.3 | 4293 | 8.3 | 33.3 | 9285 |
| 6.7 | 40.0 | 6708 | 6.7 | 40.0 | 4293 | 6.7 | 40.0 | 9285 |
| 6.7 | 46.6 | 3521 | 6.7 | 46.6 | 2254 | 6.7 | 46.6 | 5528 |
| 3.4 | 50.0 | 3521 | 3.4 | 50.0 | 2254 | 3.4 | 50.0 | 5528 |
| 9.9 | 59.9 | 3521 | 9.9 | 59.9 | 2254 | 9.9 | 59.9 | 5528 |
| 6.7 | 66.6 | 3521 | 6.7 | 66.6 | 2254 | 6.7 | 66.6 | 5528 |
| 6.7 | 73.3 | 3521 | 6.7 | 73.3 | 2254 | 6.7 | 73.3 | 5528 |
| 6.7 | 79.9 | 3521 | 6.7 | 79.9 | 2254 | 6.7 | 79.9 | 5528 |
| 40.1 | 120.0 | 6708 | 40.1 | 120.0 | 4293 | 40.1 | 120.0 | 9285 |
| 44.9 | 164.9 | 6708 | 44.9 | 164.9 | 4293 | 44.9 | 164.9 | 9285 |
| 85.0 | 249.9 | 6708 | 85.0 | 249.9 | 4293 | 85.0 | 249.9 | 9285 |

Table 2.3.2-1: (Continued)

| Profile 1 (P1) | | | Profile 2 (P2) | | | Profile 3 (P3) | | |
|---|---|---|---|---|---|---|---|---|
| Thickness (ft) | Depth (ft) | Vs (ft/s) | Thickness (ft) | Depth (ft) | Vs (ft/s) | Thickness (ft) | Depth (ft) | Vs (ft/s) |
| 100.0 | 349.9 | 6733 | 100.0 | 349.9 | 4309 | 100.0 | 349.9 | 9285 |
| 100.0 | 449.9 | 6783 | 100.0 | 449.9 | 4341 | 100.0 | 449.9 | 9285 |
| 50.1 | 500.0 | 6833 | 50.1 | 500.0 | 4373 | 50.1 | 500.0 | 9285 |
| 150.1 | 650.0 | 6883 | 150.1 | 650.0 | 4405 | 150.1 | 650.0 | 9285 |
| 100.0 | 750.0 | 6933 | 100.0 | 750.0 | 4437 | 100.0 | 750.0 | 9285 |
| 100.0 | 850.0 | 6983 | 100.0 | 850.0 | 4469 | 100.0 | 850.0 | 9285 |
| 100.0 | 950.0 | 7033 | 100.0 | 950.0 | 4501 | 100.0 | 950.0 | 9285 |
| 100.0 | 1050.0 | 7083 | 100.0 | 1050.0 | 4533 | 100.0 | 1050.0 | 9285 |
| 100.0 | 1150.0 | 7133 | 100.0 | 1150.0 | 4565 | 100.0 | 1150.0 | 9285 |
| 100.0 | 1250.0 | 7183 | 100.0 | 1250.0 | 4597 | 100.0 | 1250.0 | 9285 |
| 100.0 | 1350.0 | 7233 | 100.0 | 1350.0 | 4629 | 100.0 | 1350.0 | 9285 |
| 100.0 | 1450.0 | 7283 | 100.0 | 1450.0 | 4661 | 100.0 | 1450.0 | 9285 |
| 100.0 | 1550.0 | 7333 | 100.0 | 1550.0 | 4693 | 100.0 | 1550.0 | 9285 |
| 100.0 | 1650.0 | 7383 | 100.0 | 1650.0 | 4725 | 100.0 | 1650.0 | 9285 |
| 100.0 | 1750.0 | 7433 | 100.0 | 1750.0 | 4757 | 100.0 | 1750.0 | 9285 |
| 100.0 | 1850.0 | 7483 | 100.0 | 1850.0 | 4789 | 100.0 | 1850.0 | 9285 |
| 100.0 | 1950.0 | 7533 | 100.0 | 1950.0 | 4821 | 100.0 | 1950.0 | 9285 |
| 100.0 | 2050.0 | 7583 | 100.0 | 2050.0 | 4853 | 100.0 | 2050.0 | 9285 |
| 100.0 | 2150.0 | 7633 | 100.0 | 2150.0 | 4885 | 100.0 | 2150.0 | 9285 |
| 100.0 | 2250.0 | 7683 | 100.0 | 2250.0 | 4917 | 100.0 | 2250.0 | 9285 |
| 100.0 | 2350.0 | 7733 | 100.0 | 2350.0 | 4949 | 100.0 | 2350.0 | 9285 |
| 100.0 | 2450.0 | 7783 | 100.0 | 2450.0 | 4981 | 100.0 | 2450.0 | 9285 |
| 100.0 | 2550.0 | 7833 | 100.0 | 2550.0 | 5013 | 100.0 | 2550.0 | 9285 |
| 100.0 | 2650.0 | 7883 | 100.0 | 2650.0 | 5045 | 100.0 | 2650.0 | 9285 |
| 100.0 | 2750.0 | 7933 | 100.0 | 2750.0 | 5077 | 100.0 | 2750.0 | 9285 |
| 100.0 | 2850.0 | 7983 | 100.0 | 2850.0 | 5109 | 100.0 | 2850.0 | 9285 |
| 100.0 | 2950.0 | 8033 | 100.0 | 2950.0 | 5141 | 100.0 | 2950.0 | 9285 |
| 100.0 | 3050.0 | 8083 | 100.0 | 3050.0 | 5173 | 100.0 | 3050.0 | 9285 |
| 100.0 | 3150.0 | 8133 | 100.0 | 3150.0 | 5205 | 100.0 | 3150.0 | 9285 |
| 100.0 | 3250.0 | 8183 | 100.0 | 3250.0 | 5237 | 100.0 | 3250.0 | 9285 |
| 3280.8 | 6530.9 | 9285 | 3280.8 | 6530.9 | 9285 | 3280.8 | 6530.9 | 9285 |

#### 2.3.2.1 Shear Modulus and Damping Curves

No site-specific nonlinear dynamic material properties were determined in the initial siting of the Quad Cities station for sedimentary rocks. The rock material over the upper 500 feet was assumed[1] to have behavior that could be modeled as either linear or non-linear. To represent this potential for either case in the upper 500 feet of sedimentary rock at the Quad Cities Generating Station site, two sets of shear modulus reduction and hysteretic damping curves were used. Consistent with the SPID (Reference 3), 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[1] to represent an equally plausible level of 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 feet.

#### 2.3.2.2 Kappa

For the Quad Cities station site, kappa estimates were determined using Section B-5.1.3.1 of the SPID (Reference 3) for a firm CEUS rock site. Kappa for a firm rock site with at least 3,000 feet of sedimentary rock may be estimated from the average S wave velocity over the upper 100 feet ($V_{s100}$) of the subsurface profile while for a site with less than 3,000 feet of firm rock, kappa may be estimated with a $Q_s$ of 40 below 500 feet 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 Quad Cities station site, with about 3,250 feet of firm sedimentary rock below the SSE control point, kappa estimates were based on the average shear-wave velocity (equivalent travel time averaging procedure) over the top 100 feet for the two base-case profiles P1 and P2. For these two profiles the corresponding average (100 feet) shear-wave velocities were 4,449 ft/s, and 2,848 ft/s with corresponding kappa estimates of 0.017s and 0.028s. Profile P3 reached hard reference rock shear-wave velocities at a depth 20 to 40 feet, and again at 80 feet. For P3, the kappa contribution from the profile was 0.001s to which a kappa of 0.006s was added for the underlying hard rock resulting in a total kappa of 0.007s. The range in kappa, about the best estimate base-case value of 0.017s (profile P1) was considered to adequately reflect epistemic uncertainty in low strain damping (kappa) for the profile.

Table 2.3.2-2: Kappa values and weights used for site response analyses (Reference 16)

| Velocity Profile | Kappa(s) |
|---|---|
| P1 | 0.017 |
| P2 | 0.028 |
| P3 | 0.007 |
| | Weights |
| P1 | 0.4 |
| P2 | 0.3 |
| P3 | 0.3 |
| G/G$_{max}$ and Hysteretic Damping Curves | |
| M1 | 0.5 |
| M2 | 0.5 |

---

[1] Assumptions discussed in Section 2 are provided by EPRI engineers (Reference 16) in accordance with implementation of the SPID (Reference 3) methodology.

### 2.3.3 Randomization of Base Case Profiles

To account for the aleatory variability in dynamic material properties that is expected to occur across a site at the scale of a typical nuclear facility, variability in the assumed[1] shear-wave velocity profiles has been incorporated in the site response calculations. For the Quad Cities station site, random shear wave velocity profiles were developed from the base case profiles shown in Figure 2.3.2-1. Consistent with the discussion in Appendix B of the SPID (Reference 3), 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 (Reference 15) 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 feet and 0.15 below that depth. As specified in the SPID (Reference 3), correlation of shear wave velocity between layers was modeled using the footprint correlation model. In the correlation model, a limit of +/- 2 standard deviations about the median value in each layer was assumed[1] for the limits on random velocity fluctuations.

### 2.3.4 Input Spectra

Consistent with the guidance in Appendix B of the SPID (Reference 3), input Fourier amplitude spectra were defined for a single representative earthquake magnitude (**M** 6.5) 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 0.01g to 1.50g) were used in the site response analyses. The characteristics of the seismic source and upper crustal attenuation properties assumed[1] for the analysis of the Quad Cities station site were the same as those identified in Tables B-4, B-5, B-6 and B-7 of the SPID (Reference 3) as appropriate for typical CEUS sites.

### 2.3.5 Methodology

To perform the site response analyses for the Quad Cities station site, 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 (Reference 3). The guidance contained in Appendix B of the SPID (Reference 3) 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 Quad Cities station site.

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[1] Assumptions discussed in Section 2 are provided by EPRI engineers (Reference 16) in accordance with implementation of the SPID (Reference 3) methodology.

### 2.3.6 Amplification Functions

The results of the site response analysis consist of amplification factors (5% critical damping 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 (Reference 3), 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 rock $G/G_{max}$ and hysteretic damping curves (model M1). 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 Quad Cities station site, Figure 2.3.6-2 shows the corresponding amplification factors developed with linear analyses (model M2). Little difference is seen over all loading levels for structural frequencies less than about 20 Hz. Tabulated values of amplification factors are provided in Tables A-2b1 and A-2b2 in Appendix A.

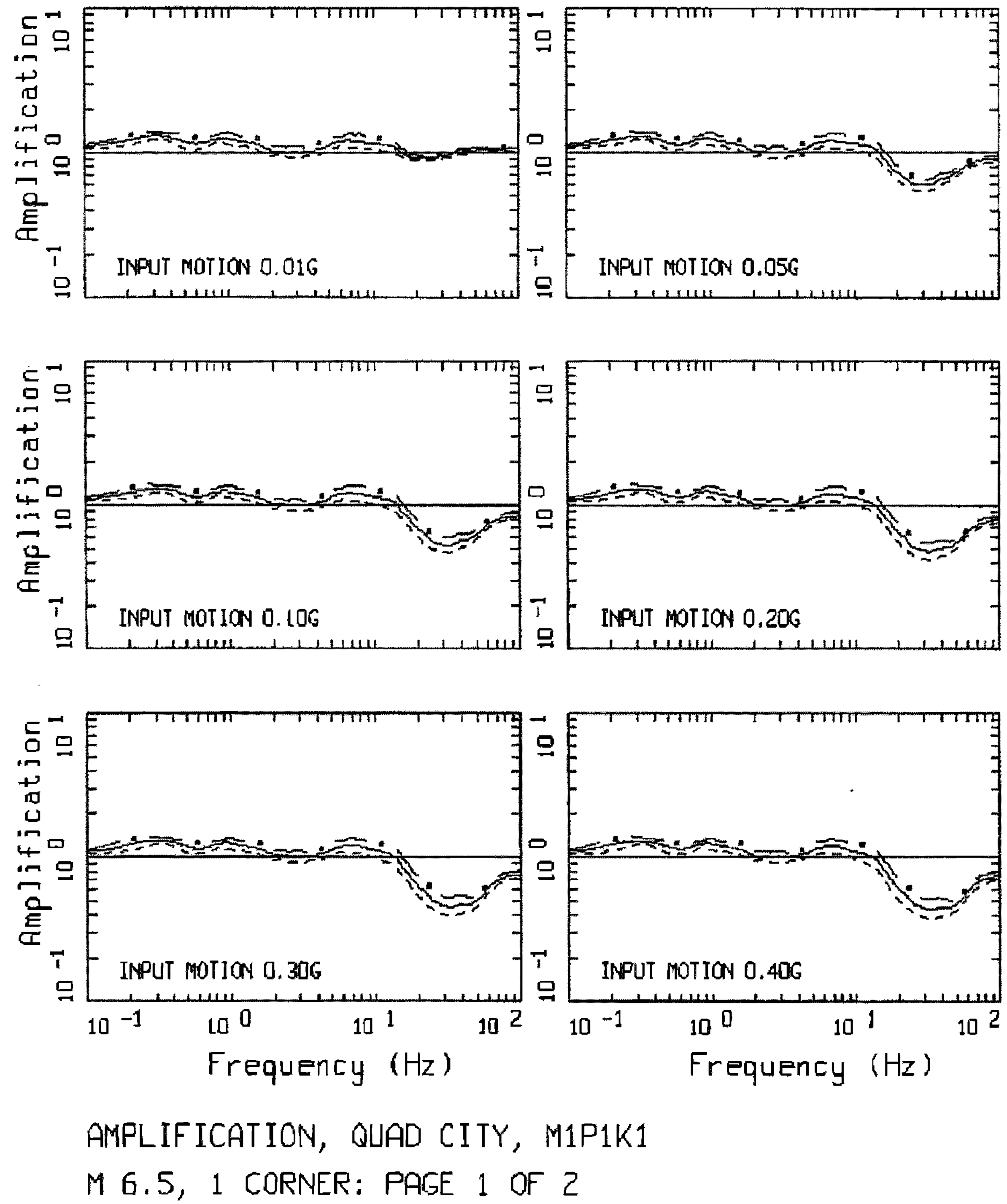
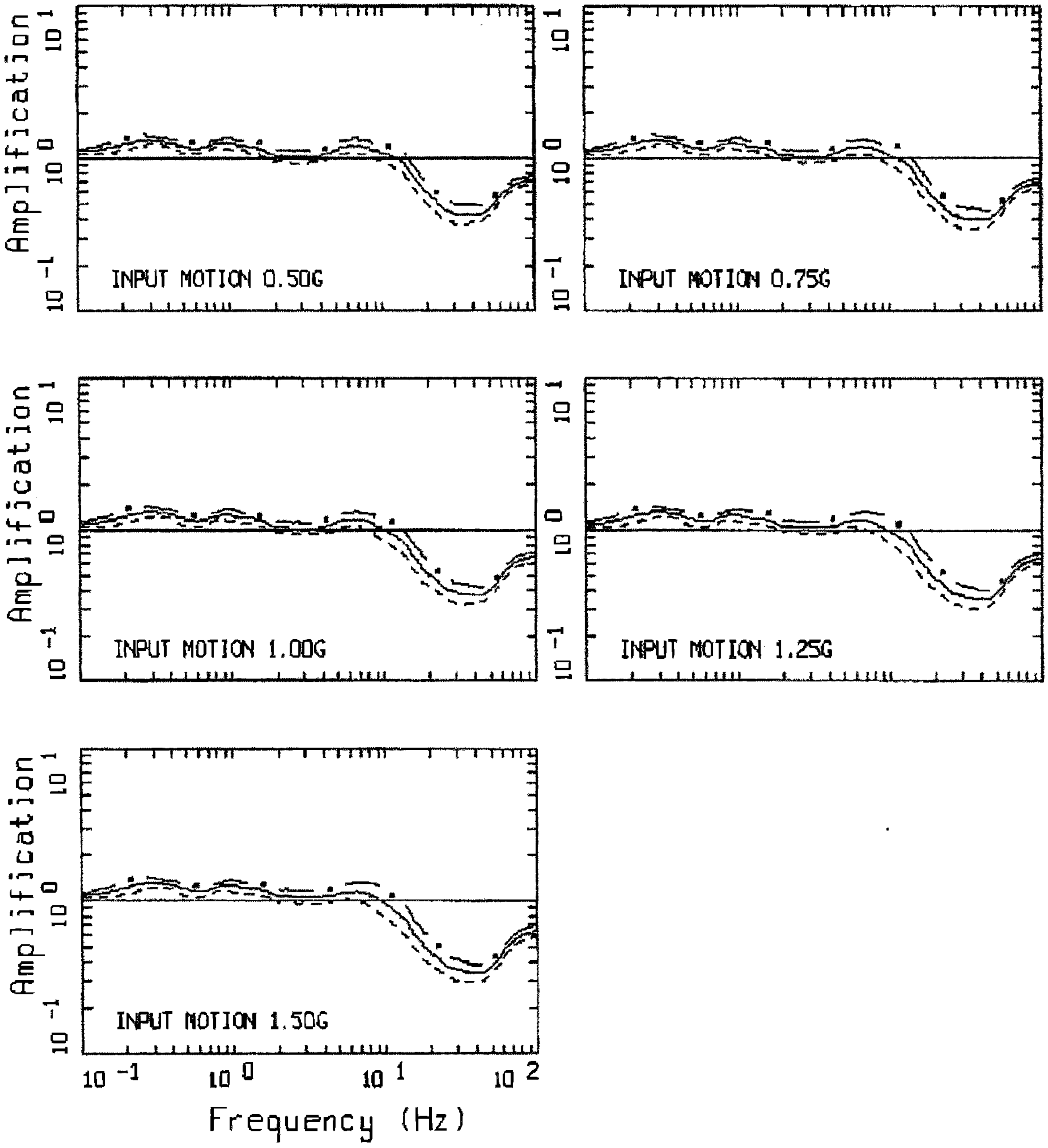


Figure 2.3.6-1: Example suite of amplification factors (5% critical damping pseudo absolute acceleration spectra) developed for the mean base-case profile (P1), EPRI rock modulus reduction and hysteretic damping curves (model M1), and base-case kappa at eleven loading levels of hard rock median peak acceleration values from 0.01g to 1.50g. **M** 6.5 and single-corner source model (Reference 3). (Reference 16)



AMPLIFICATION, QUAD CITY, M1P1K1

M 6.5, 1 CORNER: PAGE 2 OF 2

Figure 2.3.6-1 (Continued) (Reference 16)

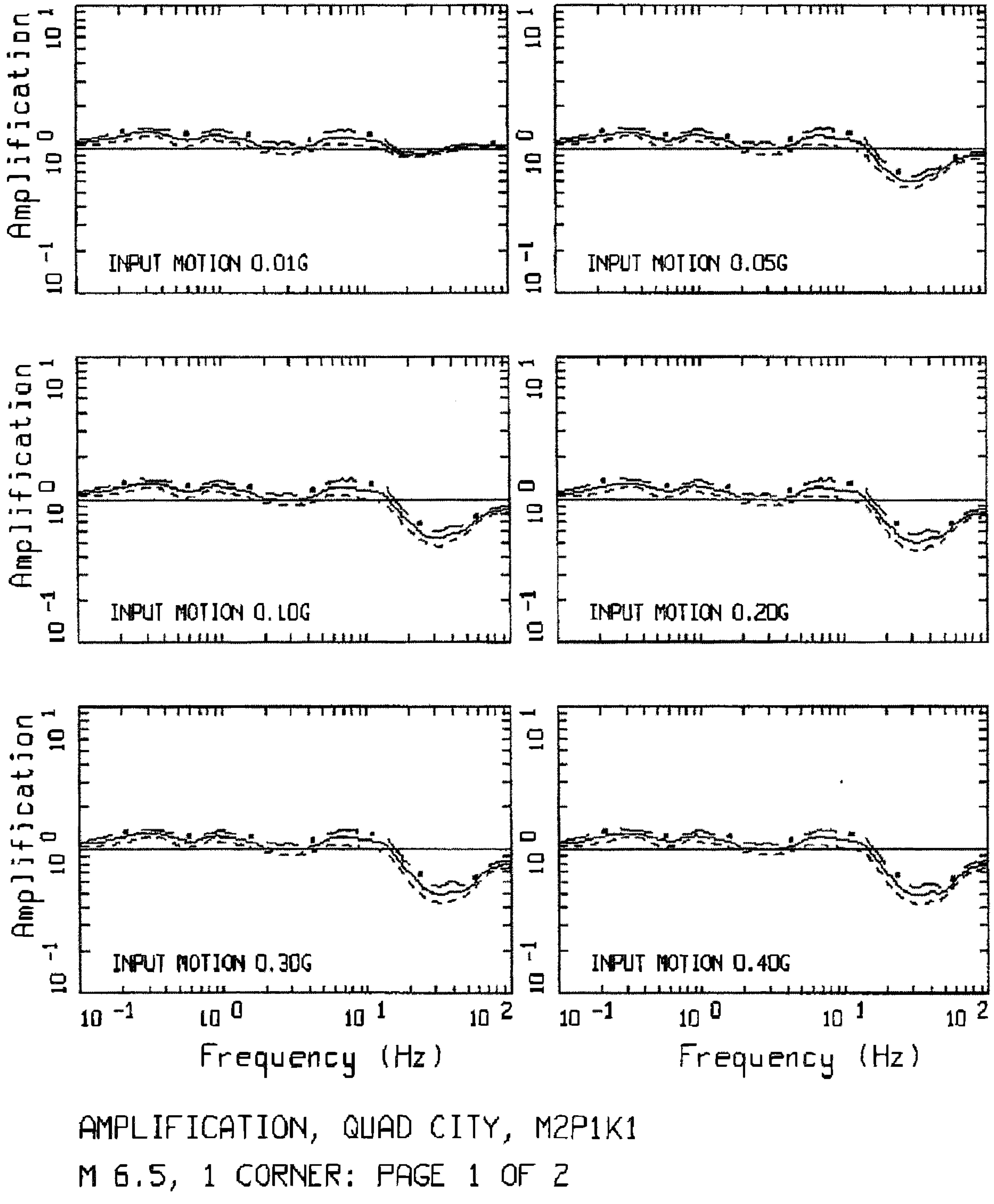
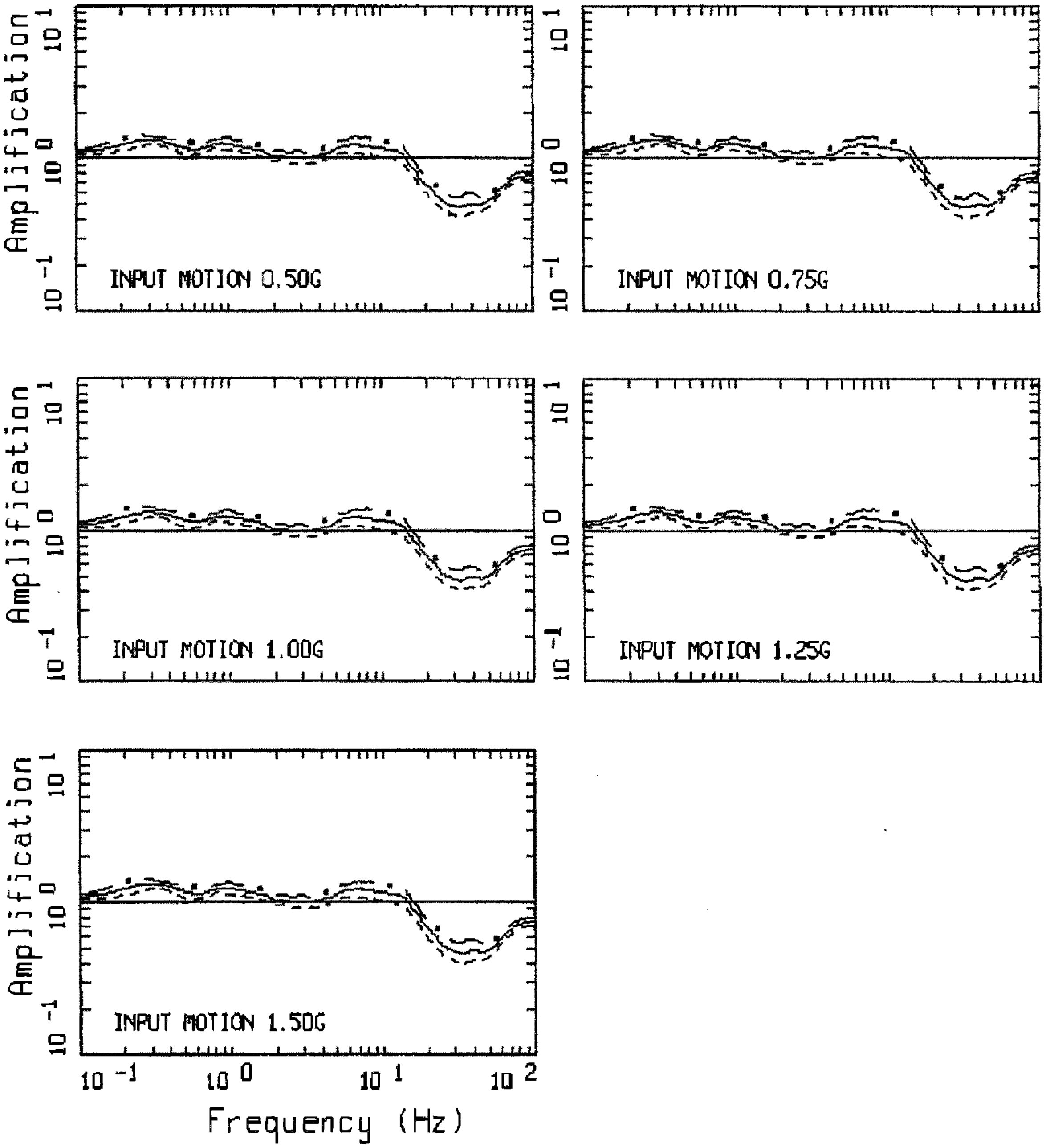


Figure 2.3.6-2: Example suite of amplification factors (5% critical damping pseudo absolute acceleration spectra) developed for the mean base-case profile (P1), linear analyses (model M2), and base-case kappa at eleven loading levels of hard rock median peak acceleration values from 0.01g to 1.50g. **M** 6.5 and single-corner source model (Reference 3). (Reference 16)



AMPLIFICATION, QUAD CITY, M2P1K1

M 6.5, 1 CORNER: PAGE 2 OF 2

Figure 2.3.6-2 (Continued) (Reference 16)

### 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 (Reference 3). 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 spectral frequencies for which ground motion equations are available. 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 Quad Cities are shown in Figure 2.3.7-1 for the seven spectral frequencies for which ground motion equations are defined. Tabulated values of mean and fractile seismic hazard curves and site response amplification functions are provided in Appendix A.

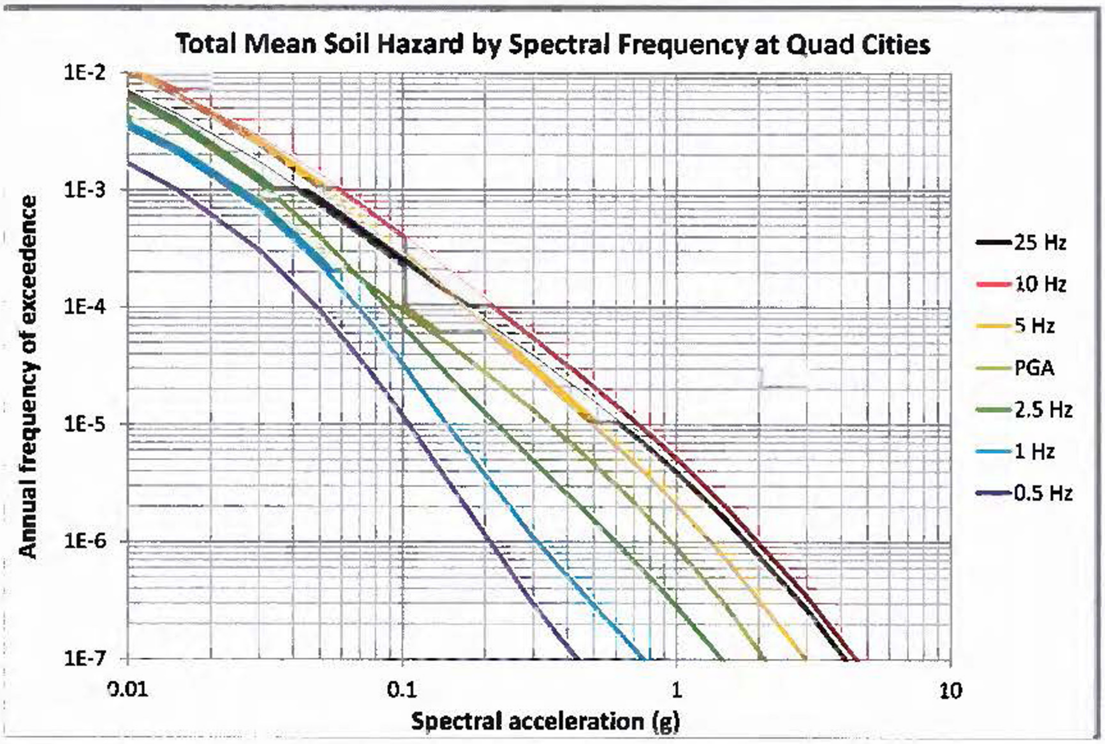


Figure 2.3.7-1: Control point mean hazard curves for spectral frequencies of 0.5, 1, 2.5, 5, 10, 25 and 100 Hz (PGA) at Quad Cities station (5% critical damping) (Reference 16)

## 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 spectral frequency for the 1E-4 and 1E-5 per year hazard levels.

The 1E-4 and 1E-5 UHRS, along with a design factor (DF) are used to compute the GMRS at the control point using the criteria in Regulatory Guide 1.208 (Reference 17). Table 2.4-1 shows the UHRS and GMRS accelerations for a range of spectral frequencies.

Table 2.4-1: UHRS and GMRS at the control point for Quad Cities station (5% of critical damping) (Reference 16)

| Freq. (Hz) | $10^{-4}$ UHRS (g) | $10^{-5}$ UHRS (g) | GMRS (g) |
|---|---|---|---|
| 100 | 9.71E-02 | 3.44E-01 | 1.60E-01 |
| 90 | 9.77E-02 | 3.48E-01 | 1.62E-01 |
| 80 | 9.88E-02 | 3.54E-01 | 1.65E-01 |
| 70 | 1.01E-01 | 3.68E-01 | 1.70E-01 |
| 60 | 1.07E-01 | 4.01E-01 | 1.85E-01 |
| 50 | 1.18E-01 | 4.57E-01 | 2.09E-01 |
| 40 | 1.32E-01 | 5.15E-01 | 2.36E-01 |
| 35 | 1.39E-01 | 5.39E-01 | 2.47E-01 |
| 30 | 1.49E-01 | 5.70E-01 | 2.61E-01 |
| 25 | 1.65E-01 | 6.23E-01 | 2.86E-01 |
| 20 | 1.86E-01 | 6.89E-01 | 3.18E-01 |
| 15 | 2.12E-01 | 7.54E-01 | 3.51E-01 |
| 12.5 | 2.19E-01 | 7.63E-01 | 3.56E-01 |
| 10 | 2.15E-01 | 7.28E-01 | 3.42E-01 |
| 9 | 2.10E-01 | 6.97E-01 | 3.29E-01 |
| 8 | 2.05E-01 | 6.66E-01 | 3.16E-01 |
| 7 | 1.94E-01 | 6.19E-01 | 2.95E-01 |
| 6 | 1.80E-01 | 5.63E-01 | 2.69E-01 |
| 5 | 1.61E-01 | 4.95E-01 | 2.37E-01 |
| 4 | 1.32E-01 | 3.83E-01 | 1.86E-01 |
| 3.5 | 1.19E-01 | 3.31E-01 | 1.62E-01 |
| 3 | 1.04E-01 | 2.77E-01 | 1.37E-01 |
| 2.5 | 8.73E-02 | 2.21E-01 | 1.10E-01 |
| 2 | 8.54E-02 | 2.08E-01 | 1.04E-01 |

Table 2.4-1: (Continued)

| Freq. (Hz) | $10^{-4}$ UHRS (g) | $10^{-5}$ UHRS (g) | GMRS (g) |
|---|---|---|---|
| 1.5 | 7.76E-02 | 1.79E-01 | 9.07E-02 |
| 1.25 | 7.35E-02 | 1.63E-01 | 8.35E-02 |
| 1 | 6.87E-02 | 1.46E-01 | 7.52E-02 |
| 0.9 | 6.46E-02 | 1.38E-01 | 7.10E-02 |
| 0.8 | 6.02E-02 | 1.29E-01 | 6.65E-02 |
| 0.7 | 5.62E-02 | 1.21E-01 | 6.23E-02 |
| 0.6 | 5.25E-02 | 1.13E-01 | 5.83E-02 |
| 0.5 | 4.85E-02 | 1.06E-01 | 5.42E-02 |
| 0.4 | 3.88E-02 | 8.45E-02 | 4.34E-02 |
| 0.35 | 3.40E-02 | 7.39E-02 | 3.80E-02 |
| 0.3 | 2.91E-02 | 6.34E-02 | 3.25E-02 |
| 0.25 | 2.43E-02 | 5.28E-02 | 2.71E-02 |
| 0.2 | 1.94E-02 | 4.22E-02 | 2.17E-02 |
| 0.15 | 1.46E-02 | 3.17E-02 | 1.63E-02 |
| 0.125 | 1.21E-02 | 2.64E-02 | 1.36E-02 |
| 0.1 | 9.71E-03 | 2.11E-02 | 1.08E-02 |

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.

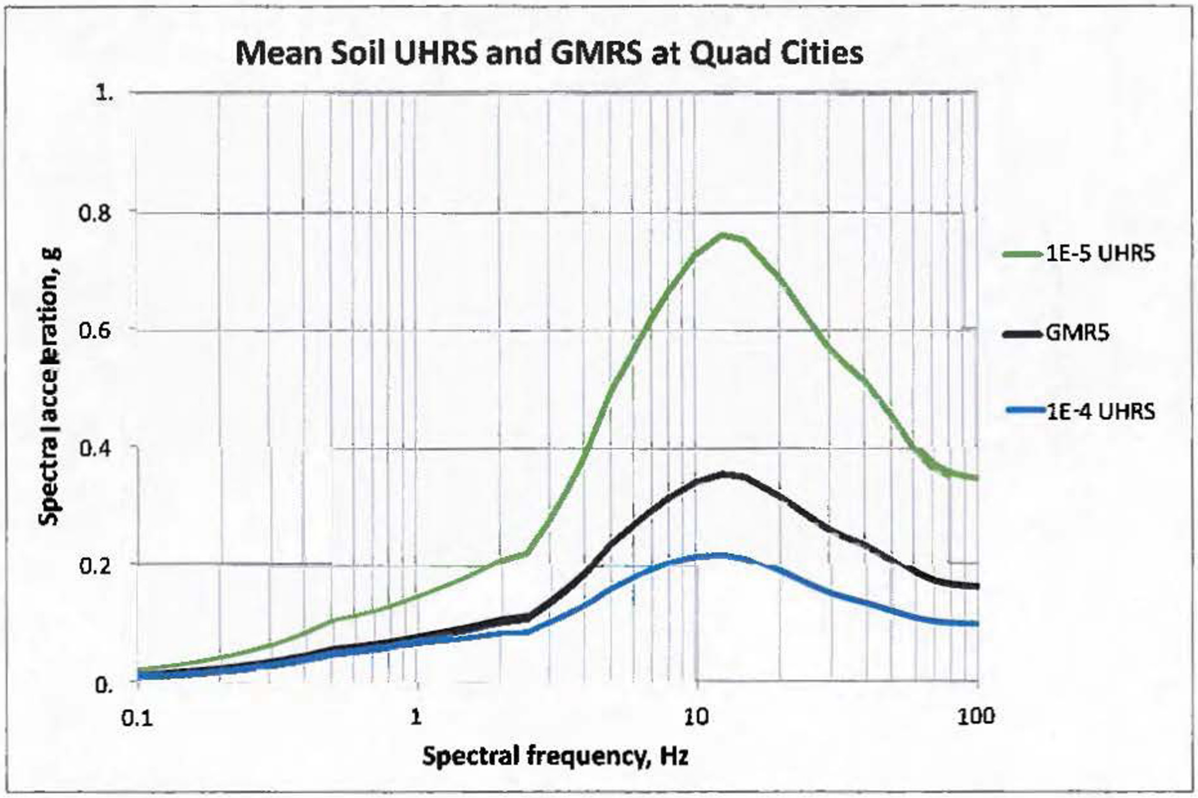


Figure 2.4-1: Plots of 1E-4 and 1E-5 UHRS and GMRS at control point for Quad Cities station (5% critical damping response spectra). (Reference 16)

# 3

# Plant Design Basis Ground Motion

The seismic design criteria for Quad Cities station was developed based on a review of historic seismology, site geology, and other site data. At the time that purchase specifications were written for the site, seismic requirements were specified to be equivalent to the maximum ground motion accelerations. As such, various methods were used to analyze and design structures and components at Quad Cities station to meet the seismic design requirements defined in terms of the maximum ground motion acceleration. (Section 3.7, Reference 10)

The Quad Cities station SSE design ground motion is defined by three input design spectra per Section 3.7 of the UFSAR (Reference 10). Initial seismic analyses unique to Quad Cities station were performed using the Golden Gate Park spectra from the San Francisco earthquake of 1957. The Dresden station drywell analysis was used to obtain loads for the Quad Cities station drywell design. The Dresden station drywell analysis was based on the El Centro earthquake of 1940. Subsequent to these initial analyses, a re-evaluation was performed using the Housner spectrum.

The original recommended seismic design criteria for structures and equipment were based on the John A. Blume and Associates report (Reference 18). The seismic criteria defined the Operating Basis Earthquake (OBE) in terms of a peak horizontal ground acceleration of 0.12g, and the SSE (also termed Design Basis Earthquake (DBD)) as twice the OBE, or 0.24g. For structures and equipment originally analyzed using the response spectrum method, the curves shown in Figure 3.7-1 of the UFSAR (Reference 10) were used. For structures analyzed using the time history method, the earthquake input corresponding to the Golden Gate Park south 80° east (S80E) component of the 1957 San Francisco earthquake normalized to 0.12g at the base of the reactor building (hereafter referred to as the Golden Gate Park earthquake) was used.

A re-evaluation of all Class I structures, piping, and equipment was performed using the Housner spectrum normalized to 0.12g due to the fact that the Housner spectrum is greater than the Golden Gate Park spectrum for frequencies less than 3.77 Hz (Section 3.7.1 and Figure 3.7-2, Reference 10). Class I structures were qualified using the design envelopes of the Golden Gate Park and Housner analyses (Section 3.7.2.1, Reference 10).

Design response spectra for qualification of piping, equipment and components were originally developed using the Golden Gate Park earthquake. These spectra were subsequently broadened by 15% and adjusted for the Housner spectra for frequencies less than 3.77 Hz. The procedure used to develop the design spectra for equipment qualification is described in Section 3.7.2.1.1.3 of the UFSAR (Reference 10). The plant seismic design criteria and design spectra are documented in Appendix H of the *Topical Design Basis Document, Quad Cities Units 1 & 2 and Dresden Units 2 & 3, Structural Design Criteria* (TDBD-DQ-1) (Reference 19). The horizontal ground spectra developed based on the composite Golden Gate Park and Housner spectra are presented in Appendix H of TDBD-DQ-1.

The Quad Cities station drywell was qualified based on a comparison to the Dresden station drywell analysis. The Dresden station drywell analysis considered the north-south component of the 1940 El Centro earthquake normalized to 0.10g for an OBE (Section 3.7.1, Reference 10). The comparison was based on review of the site geology, input earthquakes, and building arrangements (Section 3.7.2.1.4, Reference 10). The critical load source on the drywell was the displacement of the reactor-turbine building at the connections to the drywell. The Dresden station displacements were greater than the Quad Cities building displacements, and therefore it was concluded that using the Dresden station design represented a conservative design (Section 3.7.2.1.4, Reference 10).

## 3.1 SSE DESCRIPTION OF SPECTRAL SHAPE

As previously discussed, the Quad Cities SSE design ground motion is defined by various input spectra, all anchored to 0.24g PGA. For structures analyzed based on the enveloped results of the Golden Gate Park and Housner earthquakes, the 5% critical damping SSE spectra are obtained by scaling the spectra provided in Figure 3.7-2 of the UFSAR (Reference 10) by a factor of two since the spectra provided in the UFSAR are the OBE spectra. The Golden Gate Park and Housner SSE spectra are provided in Table 3.1-1 and Table 3.1-2 respectively for selected frequencies between 1 Hz to 10 Hz. The 5% critical damping ground spectrum for equipment design from the seismic design criteria TDBD-DQ-1 (Reference 19) is provided in Table 3.1-3. The SSE spectra are plotted in Figure 3.1-1.

Table 3.1-1: Golden Gate Park Safe Shutdown Earthquake ground response spectrum, 5% critical damping

| Frequency (Hz) | Spectral Acceleration (g) |
|---|---|
| 1 | 0.05 |
| 1.25 | 0.08 |
| 2 | 0.15 |
| 2.5 | 0.20 |
| 3 | 0.24 |
| 3.77 | 0.38 |
| 4 | 0.45 |
| 5 | 0.76 |
| 6 | 0.54 |
| 7 | 0.62 |
| 8 | 0.89 |
| 9 | 0.76 |
| 10 | 0.64 |

Table 3.1-2: Housner Safe Shutdown Earthquake ground response spectrum, 5% critical damping

| Frequency (Hz) | Spectral Acceleration (g) |
|---|---|
| 1 | 0.21 |
| 1.25 | 0.25 |
| 2 | 0.33 |
| 2.5 | 0.36 |
| 3 | 0.38 |
| 3.77 | 0.38 |
| 4 | 0.38 |
| 5 | 0.35 |
| 6 | 0.33 |
| 7 | 0.31 |
| 8 | 0.30 |
| 9 | 0.29 |
| 10 | 0.28 |

Table 3.1-3: Quad Cities Safe Shutdown Earthquake ground response spectrum TDBD-DQ-01, 5% critical damping

| Frequency (Hz) | Spectral Acceleration (g) |
|---|---|
| 1 | 0.25 |
| 1.11 | 0.27 |
| 1.25 | 0.29 |
| 1.43 | 0.33 |
| 1.67 | 0.36 |
| 1.82 | 0.39 |
| 2 | 0.42 |
| 2.22 | 0.46 |
| 2.5 | 0.49 |
| 2.86 | 0.54 |
| 3.33 | 0.59 |
| 3.64 | 0.64 |
| 4 | 0.67 |
| 4.44 | 0.73 |
| 5 | 0.78 |
| 5.71 | 0.85 |
| 6.67 | 0.88 |
| 7.27 | 0.90 |
| 7.69 | 0.91 |
| 8.89 | 0.87 |
| 10 | 0.84 |
| 10.53 | 0.80 |
| 11.11 | 0.75 |
| 11.76 | 0.70 |

Table 3.1-3: Continued

| Frequency (Hz) | Spectral Acceleration (g) |
|---|---|
| 12.5 | 0.62 |
| 13.33 | 0.58 |
| 16 | 0.42 |
| 20 | 0.35 |
| 26.67 | 0.31 |
| 40 | 0.28 |
| 100 | 0.24 |

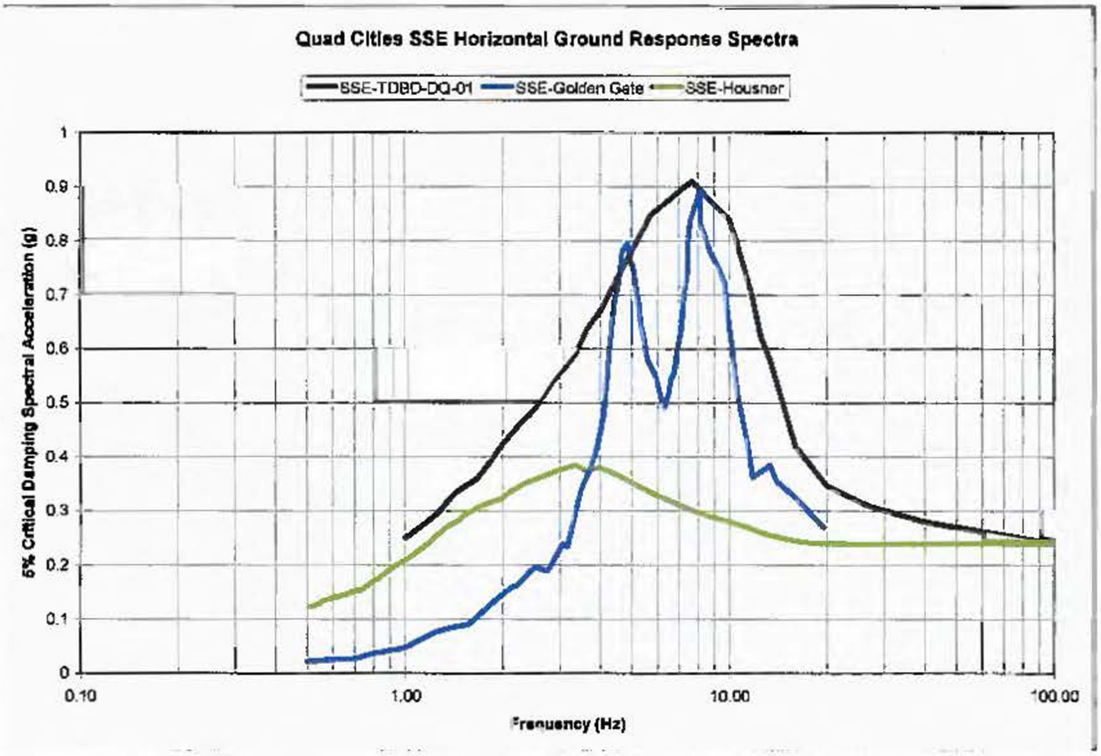


Figure 3.1-1: Quad Cities Safe Shutdown Earthquake horizontal ground response spectra (5% critical damping)

## 3.2 CONTROL POINT ELEVATION

The Quad Cities SSE was defined before the concept of a control point was defined, and the UFSAR (Reference 10) does not provide specific definition of the SSE control point elevation. Therefore, the SPID (Reference 3) Section 2.4.2 criteria were used to determine the appropriate control point elevation. Since Quad Cities is a rock site where primary safety related structures are founded on bedrock, the SSE control point elevation is defined to be at the surface of the Silurian dolomite at elevation 550 feet MSL, which is the approximate top of the bedrock in the vicinity of the reactor building.

# 4

# Screening Evaluation

Following completion of the seismic hazard reevaluation, as requested in the 50.54(f) letter (Reference 1), a screening process is needed to determine if a risk evaluation is needed. The horizontal GMRS determined from the hazard reevaluation is used to characterize the amplitude of the new seismic hazard at each of the nuclear power plant sites. The screening evaluation compares the GMRS with the established plant-level seismic capacity, in accordance with the SPID, Section 3 (Reference 3).

## 4.1 RISK EVALUATION SCREENING (1 TO 10 HZ)

As described in Section 2.4, the control point hazard curves have been used to develop the GMRS for Quad Cities station. Since structures and components at Quad Cities station have been qualified using different SSE spectra, comparisons are made for each of the three SSE spectra reported in Section 3.1 and also for the drywell which was not explicitly analyzed with a site specific spectrum.

The GMRS (Table 2.4-1) is compared to the 5% critical damping SSE Golden Gate Park (Table 3.1-1) and Housner (Table 3.1-2) spectra in the frequency range from 1 Hz to 10 Hz for the screening of structures which were based on enveloped results of the Golden Gate Park and Housner earthquakes. The Housner spectrum envelops the GMRS at frequencies less than 3.77 Hz, which was the controlling frequency range for the Housner spectrum in the original design analysis. In the frequency range greater than 3.77 Hz for which the Golden Gate Park spectrum controlled the original design, the Golden Gate Park spectrum envelopes the GMRS. Therefore, the Quad Cities controlling SSE is greater than the GMRS in the 1 Hz to 10 Hz range for structures qualified using the enveloped results of the Golden Gate Park and Housner spectra.

Piping, equipment and components internal to the plant are qualified using the Quad Cities seismic design criteria TDBD-DQ-1 (Reference 19). A comparison of the GMRS (Table 2.4-1) and 5% critical damping SSE TDBD-DQ-1 (Table 3.1-3) spectrum shows that the SSE TDBD-DQ-1 spectrum envelopes the GMRS in the 1 Hz to 10 Hz range.

The Quad Cities drywell was not explicitly analyzed for the site design earthquakes. The design is based on a comparison to the Dresden analysis. Section 3.7.2.1.4 of the UFSAR states that the controlling load source for the drywell is the reactor-turbine building displacement, and the Quad Cities building displacements are less than the Dresden displacements. It was previously determined above, that the controlling SSE for structures qualified using the Golden Gate Park and Housner spectra envelope the GMRS. Therefore, displacements will be less with the GMRS spectra input and the drywell is acceptable for the GMRS.

The Quad Cities station controlling SSE spectra envelope exceeds the GMRS in the 1 Hz to 10 Hz range. Therefore, a risk evaluation will not be performed for the Quad Cities station.

## 4.2 HIGH FREQUENCY SCREENING (> 10 HZ)

Section 3.4 of the SPID (Reference 3) discusses high-frequency exceedances. The SPID states that high-frequency vibration is not damaging, in general, to components with strain- or stress-based failure modes based on EPRI Report NP-7498 (Reference 27). EPRI Report 1015108 (Reference 28) provides evidence that supports the conclusion that high-frequency motions above about 10 Hz are not damaging to the large majority of nuclear plant structures, components, and equipment. The exception to this is relays and other electrical and instrumentation devices whose output signals could be affected by high frequency excitation.

The SSE for equipment is provided in TDBD-DQ-1, Appendix H (Reference 19). This spectrum is used for high frequency screening because it is the design spectra for equipment qualification.

Above 10 Hz, the equipment design SSE TDBD-DQ-1 exceeds the GMRS. Therefore, a high frequency confirmation will not be performed.

## 4.3 SPENT FUEL POOL EVALUATION SCREENING (1 TO 10 HZ)

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

# 5

# Interim Actions

Based on the screening evaluation outcome described in Section 4, the controlling SSE spectra envelope exceeds the GMRS in the frequency range from 1 Hz to 10 Hz and greater than 10 Hz. Therefore, no interim actions will be performed.

# 6

# Conclusions

In accordance with the 50.54(f) letter (Reference 1), a seismic hazard and screening evaluation was performed for the Quad Cities station. This reevaluation followed the SPID guidance (Reference 3) in order to develop a GMRS for the site. The GMRS was developed solely for the purpose of screening for additional evaluations in accordance with the SPID. The new GMRS represents a beyond-design-basis seismic demand and does not constitute a change in the plant design or licensing basis.

Based on the results of the screening evaluation, no further evaluations will be performed for Quad Cities station in response to the 50.54(f) letter (Reference 1).

# 7

# References

1. NRC Letter (E. J. Leeds) to All Power Reactor Licensees and Holders of Construction Permits in Active or Deferred Status, 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, March 2012

2. NRC Regulations Title 10, Code of Federal Regulations, Part 50 - Domestic Licensing of Production and Utilization Facilities

3. EPRI Technical Report 1025287, *Seismic Evaluation Guidance: Screening, Prioritization and Implementation Details (SPID) for the Resolution of Fukushima Near-Term Task Force Recommendation 2.1: Seismic*, dated February 2013

4. EPRI Technical Report 3002000704, *Seismic Evaluation Guidance: Augmented Approach for the Resolution of Fukushima Near-Term Task Force Recommendation 2.1: Seismic*, dated May 2013

5. NRC Regulations Title 10, Code of Federal Regulations, Part 100 - Reactor Site Criteria

6. NEI Letter (A. R. Pietrangelo) to the NRC, *Proposed Path Forward for NTTF Recommendation 2.1: Seismic Reevaluations*, April 2013

7. EPRI Technical Report 1021097 (NUREG-2115), *Central and Eastern United States Seismic Source Characterization for Nuclear Facilities*, dated January 2012

8. EPRI Technical Report 3002000717, *EPRI (2004, 2006) Ground-Motion Model (GMM) Review Project*, dated June 2013

9. Quad Cities Plant Design Analysis Report (PDAR), Volume I, Section 2-5.0

10. Quad Cities Nuclear Generating Station Updated Final Safety Analysis Report (UFSAR), Revision 12

11. Exelon Correspondence No. RS-12-169, Enclosure 1, *Seismic Walkdown Report In Response to the 50.54(f) Information Request Regarding Fukushima Near-Term Task Force Recommendation 2.3: Seismic for the Quad Cities Generating Station Unit 1*, dated November 2, 2012

12. Exelon Correspondence No. RS-12-169, Enclosure 2, *Seismic Walkdown Report In Response to the 50.54(f) Information Request Regarding Fukushima Near-Term Task Force Recommendation 2.3: Seismic for the Quad Cities Generating Station Unit 2*, dated November 2, 2012

13. SGH (2012). *Review of Existing Site Response Parameter Data for the Exelon Nuclear Fleet—Revision 1,* Simpson Gumpertz & Heger Rept. No. 128018-R-01 dated July 17, 2012, transmitted by letter from J. Clark to J. Hamel on July 18, 2012

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15. Toro, G., Silva, W.J., Abrahamson, N., and Costantino, C., *Description and validation of the stochastic ground motion model*, Report Submitted to Brookhaven National Laboratory, Associated Universities Inc., Upton, New York 11973, Contract No. 770573, 1997

16. EPRI RSM-121313-033, LCI Report *Quad Cities Seismic Hazard and Screening Report*, dated December 23, 2013

17. NRC Regulatory Guide 1.208, *A Performance-Based Approach to Define the Site-Specific Earthquake Ground Motion*, March 2007

18. John A. Blume & Associates, *Earthquake Design Criteria for the Quad-City Unit Number One*, May 1966

19. TDBD-DQ-1, *Topical Design Basis Document Quad Cities Units 1 & 2 and Dresden Units 2 & 3 Structural Design Criteria*, Revision 1, April 2000

20. Exelon Generation Company letter to the NRC, *Response to NRC Request for Information Pursuant to 10 CFR 50.54(f) Regarding the Seismic Aspects of Recommendation 2.1, 2.3, and 9.3 of the Near-Term Task Force Review of Insights from the Fukushima Dai-ichi Accident*, RS-13-102, dated April 29, 2013

21. Attachment 9 to Letter from Glen T. Kaegi of Exelon to U.S. Nuclear Regulatory Commission, *Quad Cities Nuclear Power Station, Units 1 and 2, Descriptions of Subsurface Materials and Properties and Base Case Velocity Profiles* (Exelon Correspondence Numbers: RS-13-205, RA-13-075, and TMI-13-104), dated September 12, 2013

22. Exelon, *Quad Cities IPEEE Submittal Report*, Revision 1, July 1999

23. NRC Letter, Endorsement of EPRI Final Draft Report 1025287, *Seismic Evaluation Guidance*, dated February 15, 2013

24. NRC Letter, EPRI Final Draft Report XXXXXX, *Seismic Evaluation Guidance: Augmented Approach for the Resolution of 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

25. NRC Letter (E. J. Leeds) to All Power Reactor Licensees and Holders of Construction Permits in Active or Deferred Status, Supplemental Information Related to Request for Information Pursuant to Title 10 of the Code of Federal Regulations 50.54(f) Regarding Seismic Hazard Reevaluations for Recommendation 2.1 of the Near-Term Task Force Review of Insights From the Fukushima Dai-Ichi Accident, February 20, 2014

26. Email from R. Kassawara (EPRI) to J. Clark (Exelon) dated February 27, 2014, Subject: Amp Tables

27. EPRI NP-7498, *Industry Approach to Severe Accident Policy Implementation*, November, 1991

28. EPRI Report 1015108, *Program on Technology Innovation: The Effects of High-Frequency Ground Motion on Structures, Components and Equipment in Nuclear Power Plants*, June 2007

# A

# Additional Tables

Table A-1a: Mean and fractile seismic hazard curves for 100 Hz (PGA) at Quad Cities, 5% of critical damping (Reference 16)

| AMPS(g) | MEAN | 0.05 | 0.16 | 0.50 | 0.84 | 0.95 |
|---|---|---|---|---|---|---|
| 0.0005 | 5.86E-02 | 2.32E-02 | 4.07E-02 | 5.83E-02 | 7.77E-02 | 8.85E-02 |
| 0.001 | 3.88E-02 | 1.38E-02 | 2.46E-02 | 3.73E-02 | 5.42E-02 | 6.64E-02 |
| 0.005 | 9.13E-03 | 2.92E-03 | 4.98E-03 | 8.12E-03 | 1.25E-02 | 1.98E-02 |
| 0.01 | 4.26E-03 | 1.20E-03 | 1.95E-03 | 3.57E-03 | 6.09E-03 | 1.05E-02 |
| 0.015 | 2.46E-03 | 6.54E-04 | 9.79E-04 | 1.87E-03 | 3.57E-03 | 7.03E-03 |
| 0.03 | 7.92E-04 | 1.69E-04 | 2.64E-04 | 5.05E-04 | 1.05E-03 | 2.84E-03 |
| 0.05 | 3.21E-04 | 5.58E-05 | 9.51E-05 | 1.92E-04 | 4.43E-04 | 1.20E-03 |
| 0.075 | 1.57E-04 | 2.46E-05 | 4.50E-05 | 9.37E-05 | 2.29E-04 | 5.58E-04 |
| 0.1 | 9.50E-05 | 1.44E-05 | 2.72E-05 | 5.91E-05 | 1.42E-04 | 3.19E-04 |
| 0.15 | 4.71E-05 | 6.64E-06 | 1.32E-05 | 3.01E-05 | 7.23E-05 | 1.46E-04 |
| 0.3 | 1.33E-05 | 1.44E-06 | 3.28E-06 | 8.72E-06 | 2.10E-05 | 3.90E-05 |
| 0.5 | 4.65E-06 | 3.28E-07 | 8.98E-07 | 2.92E-06 | 7.77E-06 | 1.42E-05 |
| 0.75 | 1.84E-06 | 7.66E-08 | 2.60E-07 | 1.04E-06 | 3.19E-06 | 6.09E-06 |
| 1. | 8.96E-07 | 2.25E-08 | 9.24E-08 | 4.56E-07 | 1.57E-06 | 3.19E-06 |
| 1.5 | 2.96E-07 | 3.14E-09 | 1.74E-08 | 1.21E-07 | 5.27E-07 | 1.15E-06 |
| 3. | 3.30E-08 | 1.32E-10 | 6.17E-10 | 7.55E-09 | 5.27E-08 | 1.44E-07 |
| 5. | 4.87E-09 | 1.01E-10 | 1.11E-10 | 6.64E-10 | 6.64E-09 | 2.25E-08 |
| 7.5 | 8.65E-10 | 9.11E-11 | 1.01E-10 | 1.42E-10 | 1.04E-09 | 4.07E-09 |
| 10. | 2.25E-10 | 8.12E-11 | 9.11E-11 | 1.02E-10 | 2.88E-10 | 1.11E-09 |

Table A-1b: Mean and fractile seismic hazard curves for 25 Hz at Quad Cities, 5% of critical damping (Reference 16)

| AMPS(g) | MEAN | 0.05 | 0.16 | 0.50 | 0.84 | 0.95 |
|---|---|---|---|---|---|---|
| 0.0005 | 6.47E-02 | 3.23E-02 | 4.77E-02 | 6.54E-02 | 8.23E-02 | 9.24E-02 |
| 0.001 | 4.62E-02 | 2.01E-02 | 3.14E-02 | 4.56E-02 | 6.09E-02 | 7.45E-02 |
| 0.005 | 1.31E-02 | 4.83E-03 | 7.34E-03 | 1.18E-02 | 1.77E-02 | 2.80E-02 |
| 0.01 | 6.75E-03 | 2.22E-03 | 3.37E-03 | 5.83E-03 | 9.51E-03 | 1.55E-02 |
| 0.015 | 4.31E-03 | 1.32E-03 | 1.98E-03 | 3.57E-03 | 6.26E-03 | 1.05E-02 |
| 0.03 | 1.67E-03 | 4.19E-04 | 6.36E-04 | 1.21E-03 | 2.49E-03 | 4.83E-03 |
| 0.05 | 7.44E-04 | 1.49E-04 | 2.39E-04 | 4.98E-04 | 1.08E-03 | 2.32E-03 |
| 0.075 | 3.77E-04 | 6.64E-05 | 1.13E-04 | 2.49E-04 | 5.50E-04 | 1.13E-03 |
| 0.1 | 2.31E-04 | 3.84E-05 | 6.93E-05 | 1.55E-04 | 3.47E-04 | 6.64E-04 |
| 0.15 | 1.17E-04 | 1.92E-05 | 3.52E-05 | 8.00E-05 | 1.82E-04 | 3.28E-04 |
| 0.3 | 3.68E-05 | 5.91E-06 | 1.18E-05 | 2.68E-05 | 5.83E-05 | 1.01E-04 |
| 0.5 | 1.51E-05 | 2.25E-06 | 4.77E-06 | 1.11E-05 | 2.46E-05 | 4.13E-05 |
| 0.75 | 7.05E-06 | 9.37E-07 | 2.04E-06 | 5.05E-06 | 1.18E-05 | 1.95E-05 |
| 1. | 3.92E-06 | 4.63E-07 | 1.04E-06 | 2.76E-06 | 6.83E-06 | 1.11E-05 |
| 1.5 | 1.59E-06 | 1.46E-07 | 3.52E-07 | 1.04E-06 | 2.84E-06 | 4.83E-06 |
| 3. | 2.66E-07 | 1.23E-08 | 3.68E-08 | 1.42E-07 | 4.98E-07 | 9.11E-07 |
| 5. | 5.64E-08 | 1.36E-09 | 4.77E-09 | 2.39E-08 | 1.04E-07 | 2.10E-07 |
| 7.5 | 1.41E-08 | 2.42E-10 | 7.89E-10 | 4.63E-09 | 2.46E-08 | 5.75E-08 |
| 10. | 4.81E-09 | 1.18E-10 | 2.42E-10 | 1.36E-09 | 8.00E-09 | 2.07E-08 |

Table A-1c: Mean and fractile seismic hazard curves for 10 Hz at Quad Cities, 5% of critical damping (Reference 16)

| AMPS(g) | MEAN | 0.05 | 0.16 | 0.50 | 0.84 | 0.95 |
|---|---|---|---|---|---|---|
| 0.0005 | 7.69E-02 | 5.20E-02 | 6.00E-02 | 7.66E-02 | 9.37E-02 | 9.93E-02 |
| 0.001 | 6.14E-02 | 3.63E-02 | 4.50E-02 | 6.09E-02 | 7.77E-02 | 8.85E-02 |
| 0.005 | 1.98E-02 | 8.85E-03 | 1.21E-02 | 1.87E-02 | 2.68E-02 | 3.52E-02 |
| 0.01 | 1.01E-02 | 4.13E-03 | 5.83E-03 | 9.24E-03 | 1.38E-02 | 1.92E-02 |
| 0.015 | 6.52E-03 | 2.46E-03 | 3.52E-03 | 5.91E-03 | 9.24E-03 | 1.31E-02 |
| 0.03 | 2.78E-03 | 8.98E-04 | 1.29E-03 | 2.32E-03 | 4.19E-03 | 6.45E-03 |
| 0.05 | 1.31E-03 | 3.84E-04 | 5.50E-04 | 9.93E-04 | 1.92E-03 | 3.42E-03 |
| 0.075 | 6.69E-04 | 1.77E-04 | 2.68E-04 | 4.90E-04 | 9.51E-04 | 1.87E-03 |
| 0.1 | 4.04E-04 | 9.79E-05 | 1.55E-04 | 2.92E-04 | 5.66E-04 | 1.15E-03 |
| 0.15 | 1.94E-04 | 4.25E-05 | 7.13E-05 | 1.42E-04 | 2.80E-04 | 5.35E-04 |
| 0.3 | 5.44E-05 | 1.02E-05 | 1.92E-05 | 4.19E-05 | 8.47E-05 | 1.40E-04 |
| 0.5 | 2.10E-05 | 3.47E-06 | 7.03E-06 | 1.62E-05 | 3.37E-05 | 5.35E-05 |
| 0.75 | 9.42E-06 | 1.34E-06 | 2.88E-06 | 7.23E-06 | 1.55E-05 | 2.49E-05 |
| 1. | 5.15E-06 | 6.17E-07 | 1.42E-06 | 3.84E-06 | 8.72E-06 | 1.42E-05 |
| 1.5 | 2.06E-06 | 1.74E-07 | 4.56E-07 | 1.40E-06 | 3.57E-06 | 6.09E-06 |
| 3. | 3.44E-07 | 1.15E-08 | 4.01E-08 | 1.90E-07 | 6.36E-07 | 1.20E-06 |
| 5. | 7.49E-08 | 9.65E-10 | 4.31E-09 | 3.19E-08 | 1.38E-07 | 2.92E-07 |
| 7.5 | 1.93E-08 | 1.67E-10 | 6.26E-10 | 6.17E-09 | 3.47E-08 | 8.23E-08 |
| 10. | 6.80E-09 | 1.02E-10 | 1.92E-10 | 1.72E-09 | 1.15E-08 | 3.01E-08 |

Table A-1d: Mean and fractile seismic hazard curves for 5 Hz at Quad Cities, 5% of critical damping (Reference 16)

| AMPS(g) | MEAN | 0.05 | 0.16 | 0.50 | 0.84 | 0.95 |
|---|---|---|---|---|---|---|
| 0.0005 | 7.87E-02 | 5.35E-02 | 6.17E-02 | 7.89E-02 | 9.51E-02 | 9.93E-02 |
| 0.001 | 6.46E-02 | 3.68E-02 | 4.63E-02 | 6.36E-02 | 8.23E-02 | 9.37E-02 |
| 0.005 | 2.12E-02 | 8.85E-03 | 1.23E-02 | 1.98E-02 | 3.01E-02 | 3.73E-02 |
| 0.01 | 1.02E-02 | 3.95E-03 | 5.83E-03 | 9.51E-03 | 1.46E-02 | 1.87E-02 |
| 0.015 | 6.33E-03 | 2.25E-03 | 3.42E-03 | 5.83E-03 | 9.24E-03 | 1.20E-02 |
| 0.03 | 2.44E-03 | 7.23E-04 | 1.11E-03 | 2.07E-03 | 3.79E-03 | 5.42E-03 |
| 0.05 | 1.03E-03 | 2.76E-04 | 4.19E-04 | 8.00E-04 | 1.57E-03 | 2.64E-03 |
| 0.075 | 4.78E-04 | 1.18E-04 | 1.84E-04 | 3.52E-04 | 6.93E-04 | 1.29E-03 |
| 0.1 | 2.68E-04 | 6.26E-05 | 1.01E-04 | 1.95E-04 | 3.79E-04 | 7.23E-04 |
| 0.15 | 1.16E-04 | 2.53E-05 | 4.25E-05 | 8.60E-05 | 1.69E-04 | 3.09E-04 |
| 0.3 | 2.80E-05 | 5.35E-06 | 1.01E-05 | 2.22E-05 | 4.43E-05 | 7.13E-05 |
| 0.5 | 9.78E-06 | 1.60E-06 | 3.33E-06 | 7.89E-06 | 1.60E-05 | 2.49E-05 |
| 0.75 | 4.05E-06 | 5.58E-07 | 1.25E-06 | 3.19E-06 | 6.73E-06 | 1.07E-05 |
| 1. | 2.07E-06 | 2.42E-07 | 5.75E-07 | 1.57E-06 | 3.47E-06 | 5.66E-06 |
| 1.5 | 7.39E-07 | 6.36E-08 | 1.69E-07 | 5.20E-07 | 1.27E-06 | 2.19E-06 |
| 3. | 9.80E-08 | 3.95E-09 | 1.27E-08 | 5.42E-08 | 1.72E-07 | 3.47E-07 |
| 5. | 1.75E-08 | 4.07E-10 | 1.31E-09 | 7.03E-09 | 2.96E-08 | 7.13E-08 |
| 7.5 | 3.87E-09 | 1.21E-10 | 2.25E-10 | 1.13E-09 | 6.09E-09 | 1.72E-08 |
| 10. | 1.22E-09 | 1.01E-10 | 1.13E-10 | 3.19E-10 | 1.77E-09 | 5.66E-09 |

Table A-1e: Mean and fractile seismic hazard curves for 2.5 Hz at Quad Cities, 5% of critical damping (Reference 16)

| AMPS(g) | MEAN | 0.05 | 0.16 | 0.50 | 0.84 | 0.95 |
|---|---|---|---|---|---|---|
| 0.0005 | 7.09E-02 | 4.43E-02 | 5.35E-02 | 7.03E-02 | 8.85E-02 | 9.93E-02 |
| 0.001 | 5.28E-02 | 2.76E-02 | 3.52E-02 | 5.12E-02 | 7.13E-02 | 8.23E-02 |
| 0.005 | 1.36E-02 | 5.66E-03 | 7.89E-03 | 1.25E-02 | 1.95E-02 | 2.46E-02 |
| 0.01 | 6.09E-03 | 2.25E-03 | 3.33E-03 | 5.66E-03 | 8.85E-03 | 1.15E-02 |
| 0.015 | 3.60E-03 | 1.13E-03 | 1.74E-03 | 3.23E-03 | 5.50E-03 | 7.34E-03 |
| 0.03 | 1.18E-03 | 2.64E-04 | 4.31E-04 | 9.11E-04 | 1.92E-03 | 3.05E-03 |
| 0.05 | 4.02E-04 | 7.55E-05 | 1.27E-04 | 2.76E-04 | 6.36E-04 | 1.18E-03 |
| 0.075 | 1.48E-04 | 2.60E-05 | 4.50E-05 | 9.93E-05 | 2.25E-04 | 4.50E-04 |
| 0.1 | 7.03E-05 | 1.20E-05 | 2.13E-05 | 4.77E-05 | 1.08E-04 | 2.10E-04 |
| 0.15 | 2.50E-05 | 3.90E-06 | 7.45E-06 | 1.77E-05 | 4.07E-05 | 7.23E-05 |
| 0.3 | 4.90E-06 | 5.27E-07 | 1.21E-06 | 3.47E-06 | 8.35E-06 | 1.44E-05 |
| 0.5 | 1.53E-06 | 1.02E-07 | 2.84E-07 | 9.79E-07 | 2.68E-06 | 4.83E-06 |
| 0.75 | 5.84E-07 | 2.39E-08 | 7.89E-08 | 3.33E-07 | 1.04E-06 | 2.01E-06 |
| 1. | 2.83E-07 | 7.77E-09 | 2.84E-08 | 1.44E-07 | 5.05E-07 | 1.04E-06 |
| 1.5 | 9.47E-08 | 1.36E-09 | 5.91E-09 | 3.90E-08 | 1.69E-07 | 3.79E-07 |
| 3. | 1.13E-08 | 1.25E-10 | 3.19E-10 | 2.80E-09 | 1.82E-08 | 5.12E-08 |
| 5. | 1.84E-09 | 1.01E-10 | 1.07E-10 | 3.42E-10 | 2.49E-09 | 8.72E-09 |
| 7.5 | 3.67E-10 | 9.11E-11 | 1.01E-10 | 1.16E-10 | 4.70E-10 | 1.74E-09 |
| 10. | 1.07E-10 | 8.12E-11 | 9.11E-11 | 1.01E-10 | 1.77E-10 | 5.42E-10 |

Table A-1f: Mean and fractile seismic hazard curves for 1 Hz at Quad Cities, 5% of critical damping (Reference 16)

| AMPS(g) | MEAN | 0.05 | 0.16 | 0.50 | 0.84 | 0.95 |
|---|---|---|---|---|---|---|
| 0.0005 | 4.86E-02 | 2.16E-02 | 3.09E-02 | 4.77E-02 | 6.64E-02 | 7.77E-02 |
| 0.001 | 3.08E-02 | 1.18E-02 | 1.82E-02 | 2.96E-02 | 4.31E-02 | 5.27E-02 |
| 0.005 | 7.03E-03 | 2.39E-03 | 3.79E-03 | 6.54E-03 | 1.02E-02 | 1.34E-02 |
| 0.01 | 3.40E-03 | 8.23E-04 | 1.44E-03 | 3.05E-03 | 5.35E-03 | 7.23E-03 |
| 0.015 | 2.10E-03 | 3.68E-04 | 7.03E-04 | 1.74E-03 | 3.52E-03 | 5.12E-03 |
| 0.03 | 7.11E-04 | 6.83E-05 | 1.44E-04 | 4.43E-04 | 1.29E-03 | 2.22E-03 |
| 0.05 | 2.34E-04 | 1.60E-05 | 3.57E-05 | 1.18E-04 | 4.07E-04 | 8.35E-04 |
| 0.075 | 7.91E-05 | 4.63E-06 | 1.04E-05 | 3.52E-05 | 1.27E-04 | 2.96E-04 |
| 0.1 | 3.33E-05 | 1.82E-06 | 4.13E-06 | 1.42E-05 | 5.05E-05 | 1.27E-04 |
| 0.15 | 9.09E-06 | 4.43E-07 | 1.10E-06 | 3.95E-06 | 1.40E-05 | 3.47E-05 |
| 0.3 | 1.09E-06 | 3.09E-08 | 1.02E-07 | 4.56E-07 | 1.82E-06 | 4.31E-06 |
| 0.5 | 2.87E-07 | 3.37E-09 | 1.46E-08 | 9.93E-08 | 4.63E-07 | 1.23E-06 |
| 0.75 | 1.04E-07 | 5.27E-10 | 2.84E-09 | 2.68E-08 | 1.60E-07 | 4.77E-07 |
| 1. | 4.99E-08 | 1.82E-10 | 8.72E-10 | 9.93E-09 | 7.23E-08 | 2.35E-07 |
| 1.5 | 1.66E-08 | 1.02E-10 | 1.98E-10 | 2.19E-09 | 2.10E-08 | 7.89E-08 |
| 3. | 2.05E-09 | 9.11E-11 | 1.01E-10 | 1.84E-10 | 1.82E-09 | 9.11E-09 |
| 5. | 3.51E-10 | 8.12E-11 | 9.11E-11 | 1.01E-10 | 2.84E-10 | 1.40E-09 |
| 7.5 | 7.48E-11 | 8.12E-11 | 9.11E-11 | 1.01E-10 | 1.13E-10 | 3.14E-10 |
| 10. | 2.29E-11 | 8.12E-11 | 9.11E-11 | 1.01E-10 | 1.11E-10 | 1.44E-10 |

Table A-1g: Mean and fractile seismic hazard curves for 0.5 Hz at Quad Cities, 5% of critical damping (Reference 16)

| AMPS(g) | MEAN | 0.05 | 0.16 | 0.50 | 0.84 | 0.95 |
|---|---|---|---|---|---|---|
| 0.0005 | 2.34E-02 | 1.04E-02 | 1.53E-02 | 2.25E-02 | 3.14E-02 | 3.90E-02 |
| 0.001 | 1.34E-02 | 5.58E-03 | 8.23E-03 | 1.27E-02 | 1.84E-02 | 2.42E-02 |
| 0.005 | 3.36E-03 | 7.45E-04 | 1.38E-03 | 3.01E-03 | 5.35E-03 | 7.23E-03 |
| 0.01 | 1.69E-03 | 1.79E-04 | 4.07E-04 | 1.29E-03 | 3.01E-03 | 4.56E-03 |
| 0.015 | 1.01E-03 | 6.45E-05 | 1.64E-04 | 6.36E-04 | 1.92E-03 | 3.19E-03 |
| 0.03 | 3.07E-04 | 8.47E-06 | 2.49E-05 | 1.23E-04 | 5.75E-04 | 1.25E-03 |
| 0.05 | 9.33E-05 | 1.62E-06 | 4.83E-06 | 2.72E-05 | 1.49E-04 | 4.13E-04 |
| 0.075 | 2.97E-05 | 3.95E-07 | 1.18E-06 | 6.83E-06 | 4.13E-05 | 1.32E-04 |
| 0.1 | 1.20E-05 | 1.34E-07 | 4.25E-07 | 2.49E-06 | 1.57E-05 | 5.35E-05 |
| 0.15 | 3.05E-06 | 2.57E-08 | 9.37E-08 | 5.91E-07 | 3.84E-06 | 1.32E-05 |
| 0.3 | 2.93E-07 | 1.10E-09 | 5.75E-09 | 4.83E-08 | 3.68E-07 | 1.38E-06 |
| 0.5 | 6.71E-08 | 1.49E-10 | 5.91E-10 | 7.23E-09 | 6.93E-08 | 3.37E-07 |
| 0.75 | 2.34E-08 | 1.01E-10 | 1.46E-10 | 1.49E-09 | 1.92E-08 | 1.15E-07 |
| 1. | 1.11E-08 | 1.01E-10 | 1.05E-10 | 4.90E-10 | 7.45E-09 | 5.27E-08 |
| 1.5 | 3.74E-09 | 9.11E-11 | 1.01E-10 | 1.49E-10 | 1.77E-09 | 1.55E-08 |
| 3. | 4.79E-10 | 8.12E-11 | 9.11E-11 | 1.01E-10 | 1.82E-10 | 1.46E-09 |
| 5. | 8.56E-11 | 8.12E-11 | 9.11E-11 | 1.01E-10 | 1.11E-10 | 2.53E-10 |
| 7.5 | 1.89E-11 | 8.12E-11 | 9.11E-11 | 1.01E-10 | 1.11E-10 | 1.13E-10 |
| 10. | 5.95E-12 | 8.12E-11 | 9.11E-11 | 1.01E-10 | 1.01E-10 | 1.11E-10 |

Table A-2a: Amplification functions for Quad Cities, 5% of critical damping (Reference 16)

| 100 Hz (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 | 1.08E+00 | 5.26E-02 | 1.30E-02 | 9.50E-01 | 5.53E-02 | 1.90E-02 | 1.12E+00 | 1.17E-01 | 2.09E-02 | 1.21E+00 | 1.28E-01 |
| 4.95E-02 | 9.49E-01 | 5.96E-02 | 1.02E-01 | 7.18E-01 | 1.13E-01 | 9.99E-02 | 1.10E+00 | 1.33E-01 | 8.24E-02 | 1.21E+00 | 1.30E-01 |
| 9.64E-02 | 8.95E-01 | 6.36E-02 | 2.13E-01 | 6.76E-01 | 1.30E-01 | 1.85E-01 | 1.09E+00 | 1.36E-01 | 1.44E-01 | 1.21E+00 | 1.30E-01 |
| 1.94E-01 | 8.51E-01 | 6.71E-02 | 4.43E-01 | 6.47E-01 | 1.40E-01 | 3.56E-01 | 1.08E+00 | 1.38E-01 | 2.65E-01 | 1.20E+00 | 1.29E-01 |
| 2.92E-01 | 8.29E-01 | 6.90E-02 | 6.76E-01 | 6.31E-01 | 1.45E-01 | 5.23E-01 | 1.07E+00 | 1.40E-01 | 3.84E-01 | 1.20E+00 | 1.28E-01 |
| 3.91E-01 | 8.14E-01 | 7.03E-02 | 9.09E-01 | 6.20E-01 | 1.48E-01 | 6.90E-01 | 1.06E+00 | 1.43E-01 | 5.02E-01 | 1.19E+00 | 1.25E-01 |
| 4.93E-01 | 8.03E-01 | 7.12E-02 | 1.15E+00 | 6.11E-01 | 1.50E-01 | 8.61E-01 | 1.05E+00 | 1.45E-01 | 6.22E-01 | 1.19E+00 | 1.22E-01 |
| 7.41E-01 | 7.84E-01 | 7.27E-02 | 1.73E+00 | 5.94E-01 | 1.56E-01 | 1.27E+00 | 1.03E+00 | 1.51E-01 | 9.13E-01 | 1.18E+00 | 1.23E-01 |
| 1.01E+00 | 7.69E-01 | 7.40E-02 | 2.36E+00 | 5.80E-01 | 1.61E-01 | 1.72E+00 | 1.02E+00 | 1.57E-01 | 1.22E+00 | 1.16E+00 | 1.32E-01 |
| 1.28E+00 | 7.56E-01 | 7.84E-02 | 3.01E+00 | 5.68E-01 | 1.67E-01 | 2.17E+00 | 1.01E+00 | 1.64E-01 | 1.54E+00 | 1.15E+00 | 1.52E-01 |
| 1.55E+00 | 7.46E-01 | 8.18E-02 | 3.63E+00 | 5.58E-01 | 1.73E-01 | 2.61E+00 | 9.95E-01 | 1.69E-01 | 1.85E+00 | 1.13E+00 | 1.61E-01 |
| 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 | 1.02E+00 | 9.44E-02 | 1.27E-02 | 1.26E+00 | 1.18E-01 | 8.25E-03 | 1.22E+00 | 1.10E-01 | | | |
| 7.05E-02 | 1.02E+00 | 9.42E-02 | 3.43E-02 | 1.25E+00 | 1.14E-01 | 1.96E-02 | 1.22E+00 | 1.07E-01 | | | |
| 1.18E-01 | 1.02E+00 | 9.44E-02 | 5.51E-02 | 1.25E+00 | 1.13E-01 | 3.02E-02 | 1.21E+00 | 1.06E-01 | | | |
| 2.12E-01 | 1.02E+00 | 9.58E-02 | 9.63E-02 | 1.25E+00 | 1.12E-01 | 5.11E-02 | 1.21E+00 | 1.05E-01 | | | |
| 3.04E-01 | 1.02E+00 | 9.82E-02 | 1.36E-01 | 1.25E+00 | 1.12E-01 | 7.10E-02 | 1.22E+00 | 1.05E-01 | | | |
| 3.94E-01 | 1.02E+00 | 1.02E-01 | 1.75E-01 | 1.26E+00 | 1.12E-01 | 9.06E-02 | 1.22E+00 | 1.06E-01 | | | |
| 4.86E-01 | 1.02E+00 | 1.06E-01 | 2.14E-01 | 1.26E+00 | 1.13E-01 | 1.10E-01 | 1.22E+00 | 1.06E-01 | | | |
| 7.09E-01 | 1.03E+00 | 1.19E-01 | 3.10E-01 | 1.27E+00 | 1.14E-01 | 1.58E-01 | 1.22E+00 | 1.06E-01 | | | |
| 9.47E-01 | 1.03E+00 | 1.25E-01 | 4.12E-01 | 1.27E+00 | 1.16E-01 | 2.09E-01 | 1.22E+00 | 1.07E-01 | | | |
| 1.19E+00 | 1.03E+00 | 1.48E-01 | 5.18E-01 | 1.28E+00 | 1.28E-01 | 2.62E-01 | 1.22E+00 | 1.16E-01 | | | |
| 1.43E+00 | 1.02E+00 | 1.58E-01 | 6.19E-01 | 1.28E+00 | 1.27E-01 | 3.12E-01 | 1.23E+00 | 1.31E-01 | | | |

Tables A-2b1 and A-2b2 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 tables concentrate on the frequency range of 0.5 Hz to 25 Hz, with values up to 100 Hz included, with a single value at 0.1 Hz included for completeness. These factors are unverified and are provided for information only. The figures should be considered the governing information.

Table A-2b1: Median AFs and sigmas for Model 1, Profile 1, for 2 PGA levels (Reference 26)

| M1P1K1 | Rock PGA=0.0964 | | | M1P1K1 | PGA=0.493 | | |
|---|---|---|---|---|---|---|---|
| Freq. (Hz) | Soil_SA | med. AF | sigma ln(AF) | Freq. (Hz) | Soil_SA | med. AF | sigma ln(AF) |
| 100.0 | 0.082 | 0.849 | 0.052 | 100.0 | 0.357 | 0.725 | 0.064 |
| 87.1 | 0.082 | 0.837 | 0.053 | 87.1 | 0.360 | 0.708 | 0.066 |
| 75.9 | 0.083 | 0.815 | 0.054 | 75.9 | 0.363 | 0.677 | 0.068 |
| 66.1 | 0.084 | 0.773 | 0.057 | 66.1 | 0.370 | 0.621 | 0.072 |
| 57.5 | 0.087 | 0.699 | 0.063 | 57.5 | 0.382 | 0.536 | 0.080 |
| 50.1 | 0.091 | 0.625 | 0.073 | 50.1 | 0.405 | 0.467 | 0.095 |
| 43.7 | 0.099 | 0.577 | 0.089 | 43.7 | 0.443 | 0.431 | 0.117 |
| 38.0 | 0.107 | 0.558 | 0.118 | 38.0 | 0.484 | 0.434 | 0.147 |
| 33.1 | 0.108 | 0.528 | 0.118 | 33.1 | 0.496 | 0.425 | 0.156 |
| 28.8 | 0.112 | 0.536 | 0.115 | 28.8 | 0.505 | 0.438 | 0.147 |
| 25.1 | 0.119 | 0.560 | 0.126 | 25.1 | 0.534 | 0.465 | 0.155 |
| 21.9 | 0.131 | 0.636 | 0.140 | 21.9 | 0.578 | 0.535 | 0.172 |
| 19.1 | 0.147 | 0.714 | 0.137 | 19.1 | 0.642 | 0.609 | 0.175 |
| 16.6 | 0.169 | 0.839 | 0.137 | 16.6 | 0.725 | 0.724 | 0.171 |
| 14.5 | 0.194 | 0.998 | 0.135 | 14.5 | 0.831 | 0.877 | 0.169 |
| 12.6 | 0.209 | 1.095 | 0.130 | 12.6 | 0.909 | 0.994 | 0.165 |
| 11.0 | 0.213 | 1.130 | 0.114 | 11.0 | 0.929 | 1.049 | 0.142 |
| 9.5 | 0.209 | 1.152 | 0.111 | 9.5 | 0.921 | 1.098 | 0.117 |
| 8.3 | 0.201 | 1.188 | 0.123 | 8.3 | 0.884 | 1.150 | 0.108 |
| 7.2 | 0.193 | 1.207 | 0.115 | 7.2 | 0.848 | 1.185 | 0.112 |
| 6.3 | 0.183 | 1.210 | 0.101 | 6.3 | 0.798 | 1.194 | 0.112 |
| 5.5 | 0.172 | 1.182 | 0.092 | 5.5 | 0.744 | 1.172 | 0.102 |
| 4.8 | 0.158 | 1.103 | 0.078 | 4.8 | 0.681 | 1.103 | 0.091 |
| 4.2 | 0.148 | 1.058 | 0.083 | 4.2 | 0.632 | 1.060 | 0.078 |
| 3.6 | 0.139 | 1.016 | 0.080 | 3.6 | 0.589 | 1.020 | 0.079 |
| 3.2 | 0.130 | 1.006 | 0.082 | 3.2 | 0.549 | 1.013 | 0.079 |
| 2.8 | 0.125 | 1.009 | 0.088 | 2.8 | 0.520 | 1.015 | 0.086 |
| 2.4 | 0.117 | 1.018 | 0.071 | 2.4 | 0.483 | 1.026 | 0.073 |
| 2.1 | 0.108 | 1.028 | 0.068 | 2.1 | 0.442 | 1.036 | 0.069 |
| 1.8 | 0.100 | 1.060 | 0.083 | 1.8 | 0.405 | 1.067 | 0.083 |
| 1.6 | 0.093 | 1.131 | 0.092 | 1.6 | 0.373 | 1.136 | 0.091 |
| 1.4 | 0.082 | 1.166 | 0.075 | 1.4 | 0.330 | 1.171 | 0.075 |
| 1.2 | 0.074 | 1.189 | 0.079 | 1.2 | 0.294 | 1.192 | 0.079 |
| 1.0 | 0.069 | 1.222 | 0.092 | 1.0 | 0.271 | 1.223 | 0.091 |
| 0.91 | 0.065 | 1.249 | 0.077 | 0.91 | 0.251 | 1.248 | 0.076 |

Table A-2b1: (cont.)

| M1P1K1 | Rock PGA=0.0964 | | | M1P1K1 | PGA=0.493 | | |
|---|---|---|---|---|---|---|---|
| Freq. (Hz) | Soil_SA | med. AF | sigma ln(AF) | Freq. (Hz) | Soil_SA | med. AF | sigma ln(AF) |
| 0.79 | 0.058 | 1.223 | 0.057 | 0.79 | 0.221 | 1.222 | 0.056 |
| 0.69 | 0.050 | 1.170 | 0.074 | 0.69 | 0.187 | 1.170 | 0.072 |
| 0.60 | 0.043 | 1.145 | 0.094 | 0.60 | 0.158 | 1.145 | 0.092 |
| 0.52 | 0.037 | 1.165 | 0.103 | 0.52 | 0.136 | 1.164 | 0.101 |
| 0.46 | 0.033 | 1.211 | 0.090 | 0.46 | 0.118 | 1.209 | 0.089 |
| 0.10 | 0.001 | 1.114 | 0.031 | 0.10 | 0.004 | 1.105 | 0.033 |

Table A-2b2: Median AFs and sigmas for Model 2, Profile 1, for 2 PGA levels (Reference 26)

| M2P1K1 | PGA=0.0964 | | | M2P1K1 | PGA=0.493 | | |
|---|---|---|---|---|---|---|---|
| Freq. (Hz) | Soil_SA | med. AF | sigma ln(AF) | Freq. (Hz) | Soil_SA | med. AF | sigma ln(AF) |
| 100.0 | 0.083 | 0.858 | 0.053 | 100.0 | 0.384 | 0.779 | 0.061 |
| 87.1 | 0.083 | 0.845 | 0.054 | 87.1 | 0.387 | 0.761 | 0.062 |
| 75.9 | 0.084 | 0.823 | 0.055 | 75.9 | 0.392 | 0.731 | 0.065 |
| 66.1 | 0.085 | 0.782 | 0.058 | 66.1 | 0.402 | 0.675 | 0.069 |
| 57.5 | 0.088 | 0.708 | 0.062 | 57.5 | 0.419 | 0.588 | 0.077 |
| 50.1 | 0.093 | 0.634 | 0.072 | 50.1 | 0.454 | 0.524 | 0.094 |
| 43.7 | 0.101 | 0.586 | 0.088 | 43.7 | 0.511 | 0.498 | 0.119 |
| 38.0 | 0.108 | 0.568 | 0.118 | 38.0 | 0.559 | 0.501 | 0.156 |
| 33.1 | 0.110 | 0.537 | 0.115 | 33.1 | 0.559 | 0.479 | 0.147 |
| 28.8 | 0.113 | 0.544 | 0.106 | 28.8 | 0.569 | 0.494 | 0.131 |
| 25.1 | 0.121 | 0.569 | 0.113 | 25.1 | 0.606 | 0.527 | 0.135 |
| 21.9 | 0.133 | 0.647 | 0.125 | 21.9 | 0.664 | 0.614 | 0.144 |
| 19.1 | 0.150 | 0.729 | 0.116 | 19.1 | 0.744 | 0.706 | 0.130 |
| 16.6 | 0.172 | 0.857 | 0.114 | 16.6 | 0.845 | 0.843 | 0.123 |
| 14.5 | 0.198 | 1.020 | 0.123 | 14.5 | 0.960 | 1.013 | 0.128 |
| 12.6 | 0.213 | 1.117 | 0.127 | 12.6 | 1.018 | 1.113 | 0.130 |
| 11.0 | 0.217 | 1.150 | 0.123 | 11.0 | 1.015 | 1.146 | 0.124 |
| 9.5 | 0.211 | 1.165 | 0.118 | 9.5 | 0.975 | 1.162 | 0.119 |
| 8.3 | 0.202 | 1.197 | 0.133 | 8.3 | 0.919 | 1.195 | 0.133 |
| 7.2 | 0.194 | 1.213 | 0.121 | 7.2 | 0.867 | 1.211 | 0.122 |
| 6.3 | 0.184 | 1.214 | 0.105 | 6.3 | 0.810 | 1.212 | 0.105 |
| 5.5 | 0.173 | 1.186 | 0.098 | 5.5 | 0.752 | 1.185 | 0.098 |
| 4.8 | 0.158 | 1.104 | 0.079 | 4.8 | 0.682 | 1.103 | 0.079 |
| 4.2 | 0.148 | 1.059 | 0.086 | 4.2 | 0.631 | 1.058 | 0.086 |
| 3.6 | 0.139 | 1.017 | 0.083 | 3.6 | 0.587 | 1.016 | 0.083 |
| 3.2 | 0.130 | 1.006 | 0.080 | 3.2 | 0.545 | 1.005 | 0.080 |
| 2.8 | 0.125 | 1.008 | 0.087 | 2.8 | 0.516 | 1.007 | 0.086 |
| 2.4 | 0.117 | 1.018 | 0.072 | 2.4 | 0.479 | 1.017 | 0.071 |

Table A-2b2: (cont.)

| M2P1K1 | | PGA=0.0964 | | M2P1K1 | | PGA=0.493 | |
|---|---|---|---|---|---|---|---|
| Freq. (Hz) | Soil_SA | med. AF | sigma ln(AF) | Freq. (Hz) | Soil_SA | med. AF | sigma ln(AF) |
| 2.1 | 0.108 | 1.028 | 0.069 | 2.1 | 0.438 | 1.027 | 0.068 |
| 1.8 | 0.100 | 1.060 | 0.083 | 1.8 | 0.402 | 1.058 | 0.083 |
| 1.6 | 0.092 | 1.131 | 0.092 | 1.6 | 0.370 | 1.128 | 0.091 |
| 1.4 | 0.082 | 1.166 | 0.074 | 1.4 | 0.327 | 1.163 | 0.073 |
| 1.2 | 0.074 | 1.189 | 0.078 | 1.2 | 0.293 | 1.186 | 0.077 |
| 1.0 | 0.069 | 1.222 | 0.091 | 1.0 | 0.270 | 1.218 | 0.090 |
| 0.91 | 0.065 | 1.249 | 0.077 | 0.91 | 0.250 | 1.244 | 0.076 |
| 0.79 | 0.058 | 1.223 | 0.057 | 0.79 | 0.220 | 1.219 | 0.056 |
| 0.69 | 0.050 | 1.170 | 0.074 | 0.69 | 0.187 | 1.168 | 0.072 |
| 0.60 | 0.043 | 1.145 | 0.094 | 0.60 | 0.158 | 1.143 | 0.092 |
| 0.52 | 0.037 | 1.165 | 0.103 | 0.52 | 0.136 | 1.163 | 0.101 |
| 0.46 | 0.033 | 1.211 | 0.090 | 0.46 | 0.118 | 1.208 | 0.089 |
| 0.10 | 0.001 | 1.114 | 0.031 | 0.10 | 0.004 | 1.105 | 0.033 |